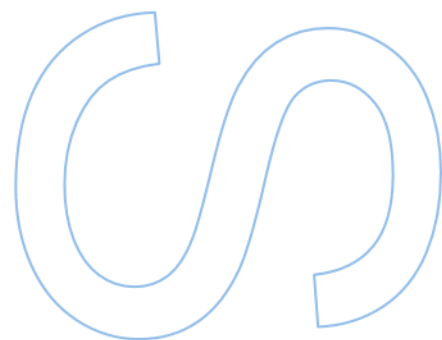
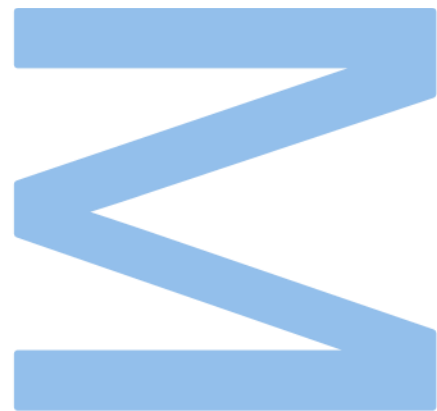


Anticipating the impacts of environmental change on plant species of conservation concern in the Iberian Peninsula

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Resumo

A biodiversidade é globalmente ameaçada pelas alterações climáticas e de uso do solo que se fazem sentir atualmente. As espécies com interesse para a conservação (SCC) estão entre umas das mais ameaçadas. No entanto, avaliar os potenciais impactos do clima e do uso do solo sob cenários de alterações futuras nas SCC é um desafio, sendo a informação sobre o uso do solo uma das principais limitações. Pretende-se contribuir para o avanço do conhecimento científico, utilizando um novo conjunto de dados que reflete a informação sobre o uso do solo, de forma a avaliar os potenciais impactos das alterações ambientais num conjunto de SCC, avaliadas e monitorizadas sobre o abrigo do Artigo 17 da Diretiva Habitats da EU. No geral, estudámos doze plantas nativas da Península Ibérica, e modelámos a sua distribuição potencial, utilizando três conjuntos de variáveis que refletem usos do solo, o clima e as condições topográficas da área de estudo. Os modelos foram calibrados para as condições atuais (2013-2017) e projetados para o futuro (2050), em três cenários diferentes de alterações de sistemas terrestres, recentemente desenvolvidos de acordo com o Quadro de Futuros da Natureza (NFF), os cenários Natureza como Cultura, Natureza pela Natureza e o Natureza para a Sociedade, respetivamente. As análises foram organizadas de forma a proporcionar uma visão geral da distribuição potencial atual e futura das SCC sob cenários de mudança, considerando as implicações para a conservação, através da análise das mudanças dentro das áreas da Rede Natura 2000 e entre categorias IUCN. No geral, os resultados mostraram uma tendência contraditória nos valores de habitat potencial da maioria das SCC, quando considerando os três cenários utilizados, revelando apenas pequenas diferenças entre os cenários. Ao considerar as categorias IUCN de espécies ameaçadas, não foi evidente nenhum padrão na avaliação do nível de ameaça das espécies. Dentro das áreas da Rede Natura 2000, a tendência foi semelhante à verificada para toda a área de estudo, com a contração do habitat potencial da maioria das espécies em estudo. Para investigação futura, o número de espécies em estudo deve ser aumentado, para a aumentar a capacidade preditiva dos modelos. Para além disso, os cenários NFF devem ser mais usados, principalmente para o estudo das alterações do uso do solo e climáticas.

Palavras-chave: alterações climáticas, alterações de uso do solo, espécies raras, espécies com interesse para conservação, Rede Natura 2000, Diretiva Habitats, SDM, modelação, Nature Futures Framework, categorias IUCN, Península Ibérica.

Abstract

Biodiversity is globally threatened by ongoing climate and land use changes. Species of Conservation Concern (SCC) are among the most threatened by such changes. However, assessing the potential impacts of climate and land use under scenarios of future change on SCCs is challenging, with information on land use being one major limitation. This research aimed to contribute to advance the field by using a novel set of data reflecting land use information, to assess the potential impacts of environmental changes on a set of SCCs assessed and monitored under the Article 17 of the EU Habitats Directive. Overall, we focused on twelve plant species native to the Iberian Peninsula and modelled their potential distribution, using three sets of predictors reflecting land systems, climate and topographic conditions of the study area. Models were calibrated for the current conditions (2013-2017) and projected for the future (2050) under three different scenarios of land systems change, recently developed according to the Nature Futures Framework, the Nature As Culture, the Nature For Nature and the Nature For Society scenarios, respectively. Analysis were organized to provide an overview on SCCs current and future potential distribution under scenarios of change, considering implications for conservation by analysing changes within the Natura 2000 areas and between IUCN categories. Overall, results showed a contracting trend of the potential habitat of most SCCs considered under the three future scenarios considered, while revealing minor differences between them. When considering the IUCN threatened categories, no clear pattern was observed when assessing the level of threat of the species. Within the Natura 2000 areas, the trend was similar to the whole study area, with the contraction of species range for the majority of the twelve species. Future research should focus on increasing the species assessed to strengthen the reported trends. Furthermore, research applying the NFF scenarios to other taxonomic groups and/or species would contribute to increasing existing knowledge and anticipating the impacts of land systems and climate change on species distributions.

Keywords: land use, land systems, climate change, rare species, species of conservation concern, Natura 2000 Network, Habitats Directive, SDM, modelling, Nature Futures Framework, IUCN threat categories, Iberian Peninsula.

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List of Abbreviations

FCUP	Faculty of Sciences of the University of Porto
UP	University of Porto
CC	Climate Change
LU	Land Use
LS	Land Systems
SP	Spain
PT	Portugal
EU	European Union
IP	Iberian Peninsula
EEA	European Environment Agency
SCC	Species of Conservation Concern
SDM	Species Distribution Models
SDG	Sustainable Development Goals
UN	United Nations
PA	Protected Area
SPA	Special Protection Area
SAC	Special Area of Conservation
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
bio1	Bioclimatic Variable 1 - Mean Annual Air Temperature
bio12	Bioclimatic Variable 12 - Annual Precipitation Amount
DEM	Digital Elevation Model
DSM	Digital Surface Model
TRI	Terrain Ruggedness Index
LU71	Forest/Shrubs and Cropland Mosaics
LU72	Forest/Shrubs and Grassland Mosaics
LU731	Low-Intensity Agricultural Mosaics
ATRBAE	<i>Atropa baetica</i>
DORPEN	<i>Dorycnium pentaphyllum</i>
EUPNEV	<i>Euphorbia nevadensis</i>
GALNIV	<i>Galanthus nivalis</i>
JUNVAL	<i>Juncus valvatus</i>
MELSEG	<i>Melilotus segetalis</i>

NARCYC	<i>Narcissus cyclamineus</i>
RHAEXA	<i>Rhaponticum exaltatum</i>
THYCAP	<i>Thymus capitellatus</i>
VERMIC	<i>Veronica micrantha</i>
VIOCAZ	<i>Viola cazorlensis</i>
XIPVUL	<i>Xiphion vulgare</i>
DD	Data Deficient
LC	Least Concern
NT	Near Threatened
VU	Vulnerable
EN	Endangered
CR	Critically Endangered
NFF	Nature Futures Framework
NAC	Nature As Culture
NFN	Nature For Nature
NFS	Nature For Society
SSP	Shared Socioeconomic Pathways
RCP	Representative Concentration Pathways
PCA	Principal Component Analysis
VIF	Variance Inflation Factor
sd	Standard Deviation
AUC	Area Under the Curve

1. Introduction

1.1. Biodiversity loss in the Anthropocene

While biodiversity can have a range of definitions, in 1992 it was defined by the Convention on Biological Diversity as “*the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems*” (United Nations, 1992a). Within this broad definition, natural ecosystems and services provided to humans, i.e., contributions of nature to humans and their well-being provided by the populations of species as well as by ecosystem functions and processes were also included (Dee et al., 2019). Biodiversity is necessary for the existence and survival of the human species and its’ sustainable development, being the foundation of human life (Prakash & Verma, 2022).

Drivers of biodiversity loss

Biodiversity is threatened by multiple drivers inducing environmental change and many species are disappearing at an alarming rate (Prakash & Verma, 2022; United Nations, 2023). This phenomenon is considered by some the sixth mass extinction period on Earth (the Anthropocene), this time accelerated by the human interference on the planet (Tang et al., 2023). Among the drivers of change, the most influential directly impacting biodiversity are habitat and/or land use change, climate change, biological invasions, overexploitation of natural resources, and pollution (Prakash & Verma, 2022). Other important factors that contribute to the global environmental change are human population growth and inequality, unsustainable production and consumption patterns, environmentally harmful subsidies and strong reliance on fossil fuels, poor governance regimes and limited recognition of the importance of biodiversity conservation (Kim et al., 2023). All these drivers can jointly impact social-ecological systems causing disruption and harm to species, habitat, and ultimately humans (Kim et al., 2023).

Climate change is a phenomenon with known effects at the local, regional, and global scales (IPCC, 1990). Overall, climate change can be defined as the long-term changes in the Earth’s climate that are warming the atmosphere, ocean, and land (UNDP, 2023). Global warming occurs when the concentration of greenhouse gases in the atmosphere increases, which absorb solar radiation and trap more heat, escalating Earth’s average surface temperature (UNDP, 2023). The principal greenhouse gases are carbon dioxide

and methane, which have been released to the atmosphere in great quantities by humans since the 1800's, due to burning of fossil fuels (for transportation, industry, or energy), deforestation, farming, and livestock. With impacts observed across the globe, climate change is becoming evident all around the world as changing weather patterns, rising of the sea level, coastal erosion, melting of glaciers, ocean warming and more frequent extreme weather events (i.e., hurricanes, heat waves, droughts), altogether disrupting economies and people's lives, as well as ecosystem services and biodiversity in general (Alves et al., 2019; Carro & Soriquer, 2017; Mingarro & Lobo, 2021; S. C. Pereira et al., 2020, 2021; Jerez et al., 2013; United Nations, 2015).

The latest reports refer that global temperature is already 1.1 °C above pre-industrial levels and likely will reach or surpass the critical 1.5 °C tipping point by 2035 (United Nations, 2023), making the last decade the hottest since known records. Carbon dioxide levels continue to rise reaching numbers not seen in 2 million years, and humanity continues to rely on fossil fuels instead of transitioning to renewable energies (i.e., solar, wind, water) (United Nations, 2023). The window of opportunity to act against climate change is rapidly narrowing, meaning that the period when significant change can be made for limiting changes within tolerable boundaries is closer each day to the tipping point (Masson-Delmotte et al., 2019).

Climate change has been affecting the physiology, distribution, and phenology of plant species (Thuiller, Lavorel, et al., 2005). When faced with environmental change (i.e., global warming), plants are forced to shift or decrease their distribution dramatically (Wang et al., 2016), and many try to shift their distribution to latitudes and/or altitudes with more suitable conditions (Long et al., 2021). This leads to the fragmentation of species' habitat, which in turn can reduce species' abilities to track the rapid climate changes (Leimu et al., 2010). When faced with adverse and changing environmental conditions, not all species can shift their habitats quickly or as easily as others, because of their specific traits and ecology. In a fragmented population, species' ability to disperse to habitats with optimal conditions is compromised, and they exhibit reduced genetic variation, lowering the adaptive potential of species under climate change (Leimu et al., 2010). If that happens, they are threatened to lose portions of their suitable habitat or become extinct in extreme cases (Long et al., 2021), unless they can find climate refugia (Oliver & Morecroft, 2014).

Humankind uses, directly or indirectly, more than 70% of the Earth land surface, being that half of the world's terrestrial area is used for agriculture, while the other half is occupied by urban areas (i.e., cities, villages, human infrastructures) and wilderness (i.e.,

forest, shrubs, fresh water) (Masson-Delmotte et al., 2019; Ritchie & Roser, 2019). Natural habitats are being threatened by humans, who turn it into agricultural land (Ritchie & Roser, 2019) or use it for other human activities, having modified around three-quarters of the global land (Moreira et al., 2023). Land use is a key driver of change with known impacts on biodiversity and ecosystem services across scales (Dou et al., 2021a; Navas et al., 2024). Land use reflects both the land cover type (i.e., arable land, improved grassland, extensive grassland) and respective management (i.e., cropping patterns, grazing regimes, etc.) (Oliver & Morecroft, 2014).

Land use change can be manifested in many ways, having great impacts on habitats and the biodiversity they support, driving species away from their range or forcing them to adjust, adapt or even live in areas with unsuitable conditions for them. Land use changes are many times related to agriculture, because of its expansion, which causes direct habitat loss and fragmentation, or due to the fertilization of the fields, that alters the levels of nitrogen available in the soil and therefore conditions the type of plants able to grow on those new conditions and can increase competition between species. Other ways land use can be evident are: urbanization and human development (areas with less history of human contact are more sensitive to land use change); isolation of populations, by artificial barriers (i.e., roads); alterations of grazing regimes, causing large impacts on local biodiversity; increasing of forest fragility; deforestation; worsening of forest fires; and overall overexploitation and pollution of land (Fernández-Nogueira & Corbelle-Rico, 2018; Navas et al., 2024; Nic Lughadha et al., 2020; Oliver & Morecroft, 2014). All this leads to changes of species demography, distribution, dispersal and behaviour.

Climate and land use changes are major drivers for the decline or disappearance of several species, so understanding their potential impacts on biodiversity is of the utmost importance to conservation planning (Alves et al., 2019; Long et al., 2021; Moreira et al., 2023; Oliver & Morecroft, 2014; Sirami et al., 2017). While climate and land use are known to interact (synergically or sometimes antagonistically) in their effects on biodiversity, not much research has considered this complexity, limiting our ability to manage habitats and landscapes appropriately (Oliver & Morecroft, 2014). As an example, land use change can affect climate at the global scale by altering the balance of carbon in terrestrial and atmospheric pools, or at the regional scale since each land cover type can impact different surface fluxes of radiation, heat, moisture, and momentum (Oliver & Morecroft, 2014). On the other hand, climate change can also influence land use, by impacting the type of climax vegetation in a location, or through changes in socioeconomic systems and policy responses (Oliver & Morecroft, 2014).

This two way interaction between climate and land use change can also vary within countries, due to regional differences in the intensity of these changes, resulting in different spatial patterns in areas that could, in theory, be expected to have similar species (Oliver & Morecroft, 2014).

Recently, research has been focussing on land systems change, and potential impacts for biodiversity (Dou et al., 2021b). Land systems represent the terrestrial component of Earth and include all processes and activities related to the human use of the land (socioeconomic, technological, and organizational) (Verburg et al., 2013). All human decisions, across scales, result in land system change and have impacts on the Earth systems, which have consequences on human well-being, decision (law) making and biodiversity in general (Verburg et al., 2013). The concept of land systems change thus goes beyond land use, as it focuses on the mutual interplay between social and ecological systems that shape land use and land cover, by considering drivers and impacts of land change as part of global environmental change, across temporal and spatial scales (Dou et al., 2021b; Verburg, 2023; Verburg et al., 2013).

The condition of the ecosystems on which humanity and all other species depend is deteriorating at a very rapid pace (United Nations, 2023). Recently, the important role of plants on the global environmental crisis has been recognized, since plant biodiversity is essential to support all types of life (Nic Lughadha et al., 2020). Plants provide essential ecosystem services to humans such as provisioning of plant products (food, timber, firewood, medicine, etc.), erosion control (cohesion of soil particles by the plant's root systems), invasion resistance (interferes with the establishment, growth, survival and reproduction of invasive species), pest regulation (regulates primary consumers that attack the ecosystems), pathogen regulation (regulates pathogen biomass that attack them), soil fertility regulation (regulates the amount and availability of nutrients in the soil) and carbon sequestration (sequestration in their biomass – below and above ground) (Quijas et al., 2010).

Biodiversity loss is among the most pressing challenges humanity faces (United Nations, 2023). Anticipating the risks species and overall biodiversity face under current environmental changes is thus essential to prioritize their conservation in the context of the rational allocation of the resources available (Nic Lughadha et al., 2020).

Pathways to halt biodiversity loss: from global to continental strategies

One of the first steps towards biodiversity preservation, with a more environmental conscious mindset by society and science was the Earth Summit (1992) in which 178 countries adopted the Agenda 21, a plan of action to build a global partnership for sustainable development, in order to improve human lives and protect the environment (United Nations, 1992b). In 2000, during the Millennium Summit, UN Member States adopted the Millennium Declaration that resulted in the elaboration of eight Millennium Development Goals, focused on reducing extreme poverty by 2015 and a commitment to the environment (United Nations, 2000). The next step towards more environmental conscious policies was at the United Nations Conference on Sustainable Development in Rio de Janeiro, Brazil (2012), where Member States launched the development of Sustainable Development Goals (SDGs), to build upon the Millennium Development Goals (United Nations, 2023). The developing process culminated in the adoption of the 2030 Agenda for Sustainable Development, with seventeen SDGs, at the 2015 UN Sustainable Development Summit in September 2015 (United Nations, 2015).

The SDGs tackle the climate crisis to preserve oceans and forests, besides the broader goals of ending poverty, improve health and education, reduce inequality, and spur economic growth. For that purpose, the United Nations dedicated one of its SDGs to protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss, the Goal 15 - Life On Land (United Nations, 2015). To achieve this goal, a fundamental shift in humanity's relationship with nature is essential (United Nations, 2023). Another relevant SDG is Goal 13 - Climate Action, which aims to integrate climate change measures into national policies, strategies, and planning; building resilience and adaptive capacity to the climate impacts and natural disasters; and improve education, raise awareness and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning (United Nations, 2015). To track the progress, the Global Sustainable Development Report is produced once every four years (United Nations, 2023). Despite the new policies and SDGs, since 2015 protected area coverage of key biodiversity areas has stalled around the world (United Nations, 2023).

The Paris Agreement on Climate Change, at the 2015 UN Climate Change Conference (COP21) in Paris, France, aimed to strengthen the global response to the threats of climate change, in the context of sustainable development and efforts to eradicate poverty, as a way of reducing its impacts and risks. Overall, the main objectives established were avoid the increase of the global average temperature to below 2 °C

above pre-industrial levels and pursue efforts to limit the temperature increase to 1,5 °C above pre-industrial levels; increase the ability to adapt to adverse impacts of climate change and foster climate resilience; lower the greenhouse gas emissions, in accordance with a climate-resilient development of finance (United Nations, 2015).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is an independent intergovernmental organ established in 2012 by 94 governments. IPBES aims to strengthen the knowledge through science, with a central mission of improving policies for the conservation and sustainable use of biodiversity, long term human well-being and sustainable development (IPBES, 2012). It responds to requests from Governments, to find solutions to their needs related to biodiversity and ecosystem services, and it also identifies and prioritizes key scientific information needed for policymakers, promoting the efforts to generate new knowledge by engaging in dialogue with key scientific organizations, policymakers, and funding organizations (but the IPBES should not directly undertake new research) (IPBES, 2012). Besides that, IPBES performs assessments of knowledge on biodiversity and ecosystem services and their connections, on a regular basis and on global, regional, and subregional scales (IPBES, 2012). These assessments are characterized by being scientifically credible, independent, and peer-reviewed, and must identify uncertainties, respecting a clear and transparent process of data processing (IPBES, 2012).

At the European Union (EU) scale, the Green Deal (COM/2019/640), plans for a modern and greener economy, to make the EU the first climate-neutral region by 2050 (European Commission, 2019). Overall, the Green Deal aims to: protect biodiversity and ecosystems; reduce air, water, and soil pollution; move towards a circular economy; improve waste management; and ensure the sustainability of blue economy and fisheries sectors (European Commission, 2019). Along with the Post-2020 Global Biodiversity Framework (GBF), the Green Deal establishes transformative targets to accomplish the no-net-loss of natural areas, to extend the protected areas and forested lands, and reduce the use of nitrogen (Dou et al., 2023). Integrated in the European Green Deal, the 2030 EU's Biodiversity Strategy consists of a long-term plan to protect nature and reverse the degradation of ecosystems towards biodiversity recovery by 2030. Published in 2020, it proposes specific actions to build resilience to threats like climate change, fires, food insecurity and disease outbreaks. Some of the actions established in the EU's Biodiversity Strategy to protect biodiversity include enlarging the EU-wide network of protected areas on land and sea, namely the Natura 2000 network (i.e. of both the Habitats Directive and the Birds Directive), and strict protection for areas of very high

biodiversity and climate value (European Commission, 2023). Such protected areas harbour important and threatened species and habitats, in great need of better and more effective conservation efforts. They are also very important for the preservation of global biodiversity, as the primary policy instrument, and they play an important role for the conservation of the habitats of wild endangered plants through in situ conservation (Ribeiro et al., 2022).

1.2. Species of conservation concern: concept, conservation, and reporting

Defining species of conservation concern (SCC)

Species rarity is considered a difficult concept to define (Jeliazkov et al., 2022). A species can be considered rare if: geographically restricted (e.g., endemic species) and/or characterized by a small population size (reflected i.e. by a low number of occurrences) (Dee et al., 2019; Lomba et al., 2010; Qazi et al., 2022); inhabits only one or few particular habitats (habitat specialization) (Lomba et al., 2010; Qazi et al., 2022; Tang et al., 2023); and are more susceptible to environmental changes (Sousa-Silva et al., 2014). Overall, rare species are more likely to be at risk and the first to be lost, because of their demographic characteristics and their vulnerability to environmental drivers, such as climate change and human activities, further leading to declining biodiversity and community stability (Dee et al., 2019; Tang et al., 2023). Rare species include threatened and endangered species (Dee et al., 2019; Lomba et al., 2010), therefore there's a pressing need to determine how environmental change, namely climate change and land use change will impact the distribution of these species, both for monitoring and preservation purposes (Lomba et al., 2010). These species can be considered species of conservation concern (SCC), needing more impactful and effective conservation efforts.

Recent research has been contradicting the role of rare species within the ecosystems, showing they can contribute directly and indirectly to their ecosystems through species interactions (Dee et al., 2019). Many times, those species are perceived as having none to minimal contribution to ecosystems services and functions, when only abundance is considered as of value for ecosystem services, because of their small ranges of distribution and considering they are the most likely to be lost from the ecosystems, leading to a number of challenges in their modelling (Dee et al., 2019; Tang et al., 2023). Still, considering their unique functional roles in certain ecosystems, some SCCs have a relevant contribution to ecosystem functions and services (Dee et al., 2019). Rare species often hold unique functional traits (i.e., characteristics that reflect adaptive strategies of species, associated with biogeochemical cycles, life histories, competition with neighbours, and toleration of diseases) that contribute to the community functional diversity (Tang et al., 2023). Functional diversity ensures that different species (both rare and common) play different or complementary roles within a community, occupy different niches, and utilize different resources, having separate contributions and enhancing the

overall productivity of the ecosystem (Mi et al., 2020). A recent study found the importance of rare species in high-diversity forest ecosystems due to their high functional diversity, while still being the most vulnerable to disturbance (Tang et al., 2023), pointing out the need to focus conservation efforts on rare plants at the community level. Other studies reported that the majority of species in many communities are rare, but they occupy outlying niches to avoid competition with common species and that such species are more important for ecosystem stability and functioning because of their narrow environmental niche width (Mi et al., 2020).

The assessment of the conservation status of species often follows the International Union for Conservation of Nature (IUCN) Red List criteria (IUCN, 2022), that considers eight categories: Not Evaluated (NE), Data Deficient (DD); Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), Extinct (EX). Overall, IUCN classification is based on the following criteria: (i) declining population (past, present, or future); (ii) a measure of geographic range (including its fragmentation, decline, or fluctuation); (iii) small population sizes and fragmentation, decline, or fluctuation; (iv) very small population size or very restricted distribution; and (v) a quantitative analysis of extinction risk (IUCN, 2012). The IUCN classification allows comparing the conservation of different species (namely SCC) from different taxonomic groups, or even the same species in different countries. Based on the IUCN classification, Red Lists are built and used to guide efforts of conservation towards SCC and other relevant species and can be applied across scales (national, regional, or global) (Keller & Bollmann, 2004; A. Rodrigues et al., 2006).

Priority areas for conservation across scales

All around the world, there's a need for more effective conservation, especially in areas that harbour threatened species, like protected areas. According to the IUCN (2008), protected areas are defined as “a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values” (IUCN, 2023). Across the globe, the latest records recognize the existence of 275 492 protected areas, covering about 16% of the of the earth's terrestrial and inland waters, and 18 200 marine protected areas, that cover 8% of the world's oceans (Protected Planet, 2024).

Biodiversity hotspots are important areas for biodiversity conservation and can be defined as “areas featuring exceptional concentrations of species richness, with

exceptional concentrations of narrow endemic species and experiencing exceptional loss of habitat” (Myers et al., 2000). Since species aren’t evenly distributed around the planet, there are 36 hotspots in the world, each holding at least 1500 plant species that are rare, endemic, or only found there, and although they only represent 2.5% of Earth’s land surface, they support more than half of the world’s endemic plant species and nearly 43% of bird, mammal, reptile, and amphibian endemic species (CEPF, 2017; Conservation International, 2023). Among the most important biodiversity hotspots are the Mediterranean Basin, the Atlantic Forest in Brazil, or Madagascar. As an example, the Mediterranean basin is the second largest biodiversity hotspot in the world and a very important area of conservation. While the Mediterranean Basin only represents 1,6% of the Earth’s surface, it hosts 10% of the world’s higher plants and 800 species of terrestrial vertebrates (CEPF, 2017; Pascual et al., 2011). Result from a particular geographic location, topography and climate, and more than 5000 years of human occupation, the Mediterranean Basin is the third richest hotspot in terms of plant diversity, with approximately 25000 species, many of them endemic to the area (CEPF, 2017; Pascual et al., 2011). Overall, while biodiversity hotspots would allow the concentration of conservation efforts into more limited areas, recent assessments report the loss of at least 70% of their original habitat extent due to human activities (CEPF, 2017).

To protect the rare and threaten species in the EU, the Natura 2000 network was designated to integrate specific areas to ensure the long-term protection and survival of EU most threatened species and habitats (European Commission, 2021a). It reflects the Habitats Directive (Council Directive 92/43/EEC) (CBD, 1992), which aims to protect EU’s wild flora and fauna (European Commission, 2021b), by designating Special Areas of Conservation (SACs) to ensure the favourable conservation status of each habitat type and species throughout their range in the EU (European Commission, 2021a), and the Birds Directive (Directive 79/409/EEC), focused on the protection of wild bird species present in the EU and their most important habitats, by designating Special Protection Areas (SPAs). The EU Habitats Directive protects 233 habitat types, and 1389 animal and plant species, and according to the latest assessment, the vast majority of protected habitats show an unfavourable conservation status (45 % poor and 36 % bad) (EEA, 2023; European Union & European Environment Agency, 2020). Bad conservation status of habitats is particularly worrying in the Atlantic and Mediterranean bioregions (European Union & European Environment Agency, 2020). In terms of protected species, reptiles, and vascular plants, have the highest proportion of good conservation status. There was a slight increase (4%) of animal and plant species with good conservation status (27%), compared with the previous report, and, overall, 60% of species are

reported to have bad (21%) and poor (42%) conservation status (European Union & European Environment Agency, 2020).

The importance of monitoring and reporting

Monitoring and reporting the state of species, namely SCC, is essential to understanding how species are rapidly changing their distribution (Arenas-Castro et al., 2018; Jetz et al., 2019). Especially for SCCs, suitable habitats need to be mapped out in an effective manner due to their restricted distributions and ease of habitat loss that is caused by environmental and anthropogenic variables (Ramachandran et al., 2020). This way, the conservation status of SCC must be continuously updated to support effective decisions on conservation policy and management (Arenas-Castro et al., 2018). For that purpose, in recent years, many reports and assessments have been carried out by IPBES and other organizations, to study the state of global biodiversity (Jetz et al., 2019). To evaluate and analyse SCC, the IUCN red-listing system is used all around the globe, since it classifies species based on strict criteria that can be used on a national, regional, or global scale (Dahlberg & Mueller, 2011; Rodrigues et al., 2006). The red list assessments document the current state of biodiversity, by including current population size, and past and predicted future developments, to develop awareness and new forms of appropriate ecosystem management (IUCN, 2022). With this classification system, we can directly compare species from different taxonomic groups and different regions (Dahlberg & Mueller, 2011), effectively managing the species that need them the most, the SCCs, through conservation action plans, recovery programs or management tools (financial or legal) (Keller & Bollmann, 2004; Nic Lughadha et al., 2020). Despite the many efforts, the Red List global assessments only cover around 30% of the plant species globally and underrepresent single-country endemic species.

In the EU, under Article 17 of the Habitats Directive, Member States must report every six years to the European Commission the conservation status of species and habitats within their territory that are part of the Habitats Directive. Such reporting implies, among other information required, to compile information on the conservation of each species as favourable, inadequate, unfavourable, or unknown, considering relevant parameters such as range, number and dimension of populations, suitable habitat, and future prospects (European Commission, 2021b). Moreover, report on the progress and implementation of the Habitats Directive follows common and harmonized formats i.e., each Member State report species records within European Environmental Agency

(EEA) Reference Grid of 10 km x 10 km ([EEA 10x10 km Reference Grid for Europe](#)) (European Environment Agency, 2011).

Reporting on the EU Habitats Directive ideally requires data reflecting species ranges and areas of potentially suitable habitat (European Commission, 2021b). Records resulting from monitoring and reporting, allow the utilization of modelling frameworks to improve the knowledge on species past and current distribution patterns or to anticipate future distributions under scenarios of potential environmental change based on known occurrences (i.e., locations where the species is present in nature) (Guisan & Zimmermann, 2000a; Sillero, 2011). Modelling frameworks are thus important tools to guide conservation and management efforts of SCC since such species are particularly vulnerable to ongoing environmental changes.

1.3. Species Distribution Models as tools to anticipate impacts of environmental change on species of conservation concern

Species distribution models (SDMs)

The study of the relationship between environment and species has always been an important and central issue in ecology. If we can understand the factors that affect the distribution of species, we will be able to geographically predict how they will respond to the changes in their surroundings (Guisan & Zimmermann, 2000). In recent years, with the biodiversity loss crisis rising, modelling tools that can predict the distribution or range of species are even more important in all fields of research, such as ecology, biogeography, conservation biology, and evolution (Guisan et al., 2007; Guisan & Thuiller, 2005; Thuiller, Richardson, et al., 2005). The identification of geographical patterns is essential for understanding how the changing environment and anthropogenic activities threaten biodiversity, especially rare and/or threatened species.

Species distribution models (SDMs) (Guisan & Thuiller, 2005; Guisan & Zimmermann, 2000) are tools developed to understand species ecological needs. They allow us to increase existing knowledge of current patterns and to predict the future of the species distribution according to expected environmental changes (extrapolate in time and space the species distribution) (Alves et al., 2019; Elith & Leathwick, 2009). SDMs combine observations of species occurrences (or abundance) with environmental estimates to gain ecological and evolutionary insights about certain species (Elith & Leathwick, 2009). These models perform well in delineating the current potential distribution of species, if the survey data is accurate (i.e., reflect all environmental gradient occupied by the targeted species), and the variables chosen are functionally relevant, resulting in an ecologically useful and insightful model with a strong predictive capability (Elith & Leathwick, 2009).

To start the modelling process, one of the first steps is to gather data about the study species and the environmental variables chosen (Elith & Leathwick, 2009). The species data used for SDM can be just simple presences (i.e., datasets consisting of confirmed presences only), presence-absence (i.e., datasets consisting of both confirmed presences and absences), or abundance observations (Guisan & Thuiller, 2005). Environmental variables can be classified as direct or indirect, based on the effect they have species, and can be arranged along a gradient from proximal to distal variables, according to the position of the variable in the sequence of processes that link to its impact on the species (Guisan & Zimmermann, 2000). According to Elith & Leathwick

(2009), other key steps of the modelling process are: assessing the comprehensiveness and relevance of the gathered data; test for correlation between variables and selection of algorithm(s); fitting of the model to the training data; evaluation of the model including the realism of fitted response functions, the model's fit to data, characteristics of residuals, and predictive performance on test data; mapping predictions to study area; selecting a threshold if continuous predictions need reduction to a binary map; and iterating the process to improve the model in light of knowledge gained throughout the process.

Various factors interfere with the effectiveness of the method chosen for modelling the species' distributions, such as the quality and quantity of the occurrence data, the environmental variables chosen, the ecological characteristics of the species, biotic interactions, and the scale of analysis (Guisan et al., 2007; Peterson & Nakazawa, 2008). For example, two species with different mobility types, will be approached differently for the modelling process, since the sessile species (i.e., plants) can be more easily characterized for its environmental requirements than a mobile one, which is always changing its location and intermittently using resources that are unevenly dispersed across a landscape (Elith & Leathwick, 2009). The scale chosen to develop the SDM's is also relevant as it relates to species responses to their environment and thus to resulting distribution patterns (Gábor et al., 2022; Guisan et al., 2007). In fact, as species can have different response scales or response grains, the chosen spatial resolution (grain) affects the ability to detect the species' response to the environmental variables (Gábor et al., 2022). Besides that, species occurrences are usually available at coarser resolutions and their conservation and management within protected areas are expected to be planned and implemented at finer resolutions (Arenas-Castro et al., 2018; McPherson et al., 2006). The grain size also reflects the spatial resolution of the available environmental data (Guisan et al., 2007). Ultimately, working at an unsuitable scale affects SDMs outcomes for the targeted species, by impacting its performance (Guisan et al., 2007).

Understanding the drivers that conditioning species' distributions is particularly relevant for SCCs, which are more vulnerable to environmental changes (Alves et al., 2019; Lomba et al., 2010; Long et al., 2021; Sousa-Silva et al., 2014). SDMs allow to forecast a species' ecological and geographic location (Qazi et al., 2022), to anticipate changes in habitat suitability or range (Alcaraz-Segura et al., 2017), providing relevant information to support conservation and monitoring efforts of SCC, i.e., reporting species' recent distribution trends (Alves et al., 2019). SDMs may also been used to assess and monitor

the impact of land use and climate change (i.e., Alves et al. (2019); Long et al. (2021); Qazi et al. (2022)), as well as other environmental changes on the distribution of species (Guisan & Zimmermann, 2000).

SDMs applied to species of conservation concern: challenges and opportunities

Rare species are often considered the hardest to account for, sample and model, at all scales (Jeliazkov et al., 2022). It is of utmost importance to gather updated knowledge and distribution data for rare species, since literature has a deficit of information on these species (Engler et al., 2004; Lomba et al., 2010). The datasets available have a low number of occurrences, aren't updated frequently or the data is gathered over long periods of time, and the spatial accuracy of the data is very limited, sometimes without valid absences (Engler et al., 2004; Lomba et al., 2010). All these characteristics are related to what researchers describe as the rare species paradox: rare species are the most in need of predictive distribution modelling (for monitoring as well as conservation management) but are the most difficult to model due to the limited number of occurrences (Breiner et al., 2015; Lomba et al., 2010).

The principal methodological challenges of modelling threatened/rare species are low number of occurrences, datasets lacking information or even a complete lack of confirmed absences (presence-only data), sampling bias and limited spatial and temporal accuracy (Alves et al., 2019; Engler et al., 2004). Many times, data isn't stored correctly or is stored in large databases, recorded by volunteers, or was even collected without a predefined sampling strategy (Engler et al., 2004). For SCCs, herbariums and museums are often used as a source of historical records, but the lack of a precise spatial location, i.e., approximate locations or common sites with a bigger margin of error (a kilometre or sometimes more), contributes to low spatial and geographical accuracy of related occurrences (Engler et al., 2004).

It has been reported that SDMs provide better estimates for more widely distributed species than for narrowly distributed species, (i.e., species of conservation concern) (Alcaraz-Segura et al., 2017; Breiner et al., 2015). For SCCs, multiple variables often become necessary for the modelling process, whereas for widely distributed species climate-only driven SDMs work the best (Alcaraz-Segura et al., 2017; Breiner et al., 2015; Lomba et al., 2010). Due to the low number of occurrences that characterizes SCCs, the number of variables that can be used in the models is reduced (Guisan & Zimmermann, 2000; Lomba et al., 2010; Sillero et al., 2021). As recommended, no more

than $n/10$ variables should be used (being n the number of occurrence records for the species) (Guisan & Zimmermann, 2000; Sillero et al., 2021).

SDMs to anticipate the impacts of change on species of conservation concern

Scenarios and models are valuable tools for exploring future outcomes of alternative social-ecological development pathways (Lundquist, Hashimoto, Denboba, et al., 2021). Besides that, they can also serve and be essential for developing and informing policy decisions (Lundquist, Hashimoto, Denboba, et al., 2021). Among the most frequently used scenarios in SDMs are the Shared Socioeconomic Pathways (SSPs) framework and the Representative Concentration Pathways (RCPs). They have a strong climate and mitigation focus and are widely used in biodiversity and climate research (Kim et al., 2023). The RCPs project future greenhouse gas concentrations (2,6; 4,5; 6; or 8 W/m²), where higher values mean higher greenhouse gas emissions, and therefore higher global surface temperatures and dire effects of climate change. The SSPs describe potential global changes considering different paths of society and respective impacts on climate in the coming decades, projecting the changes up to 2100 (O'Neill et al., 2020; Riahi et al., 2017). The SSP/RCP framework integrates societal factors by considering demography, human development (health and education), economic growth, inequality, governance, urbanization, technological change, policy orientations in relation to emissions inputs (O'Neill et al., 2020), and often considers five narratives describing alternative socio-economic developments: SSP1 -RCP2.6; SSP2; SSP3 -RCP7; SSP4; and SSP5 – RCP8.5 (Riahi et al., 2017). The SSP1- RCP2.6, entitled “taking the green road”, focuses on sustainable development and is the most positive scenario for the environment and for human development (it assumes the increase of sustainable practices) (Riahi et al., 2017). SSP2 often called the “middle of the road” scenario, presumes intermediate challenges, since income inequality persists (or improves slowly) and environmental systems experience degradation, but the intensity of resource and energy use declines overall (Riahi et al., 2017). SSP3 -RCP7, known as “a rocky road”, is very pessimistic about development and characterized by regional rivalry, and assumes a divided future with high levels of nationalism and large persistent global inequalities (Riahi et al., 2017). SSP4 called “a road divided” is characterized by inequality, where disparities in economic opportunity and political power lead to inequalities and stratification between and within countries, causing degradation of social cohesion and inciting conflict and unrest (Riahi et al., 2017). Finally, SSP5 – RCP8.5, entitled “business as usual” or “taking the highway”, focuses on fossil-fuelled

development, therefore leading to continued large negative effects on the environment (Riahi et al., 2017). Due to the current state of the world and the scenarios assumptions, SSP scenarios imply some form of biodiversity loss and ecosystem degradation across the globe, with increasing climate impact in the coming decades (Kim et al., 2023).

The Nature Futures Framework (NFF) is a novel view into future scenarios and was created because the SSP–RCP scenarios of the IPBES Global Assessment lacked information on the relationship between nature and people (Kim et al., 2023; Rosa et al., 2020). The NFF shift from traditional scenarios focusing on impacts of society on nature to nature-centred visions integrating interlinkages of social-ecological systems across drivers, biodiversity, ecosystem functions and services, and human well-being, across scale and sectors (IPBES Secretariat, 2023). The NFF was the foundation for developing scenarios of positive futures for nature and people that differ in their emphasis on the types of values that people assign to nature (Durán et al., 2023; IPBES, 2022c; IPBES Secretariat, 2023), aiming to support knowledge and communities, inviting dialogue and the creation and implementation of new management and policy interventions across scales (Kim et al., 2023).

Table 1 summarizes the three main perspectives of the Nature Futures Framework, each corresponding to one of the three scenarios envisioned (Lundquist, Hashimoto, & Schoolenberg, 2021):

Table 1 - Description of the three Nature Futures Framework perspectives: Nature As Culture (NAC), Nature For Nature (NFN) and Nature For Society (NFS) (Gasalla et al., 2022).

Nature as Culture (NAC)	Nature for Nature (NFN)	Nature for Society (NFS)
Humans are perceived as an integral part of nature, what is valued is the reciprocal character of the people–nature relationship. Relational value	Nature has value in and of itself, the preservation of nature's diversity and functions is the priority. Intrinsic value.	Value of nature - benefits or uses people derive from it, and which could lead to an optimization of multiple uses of nature. Instrumental value.
The utilitarian benefits and instrumental values that nature provides to people and societies.	Value of nature - diversity of species, habitats, ecosystems, and processes that form the natural world and nature's ability to function autonomously.	How societies, cultures, traditions, and faiths are intertwined with nature in shaping diverse biocultural landscapes.

Nature-people relationship.	Preservation of nature.	How can people use nature for their benefit?
E.g.: traditional knowledge and indigenous ways of knowing; protected areas of cultural landscape and indigenous land as co-created and co-inhabited space representing cultural values of nature (Gasalla et al., 2022).	E.g.: included aspects of protected areas, often established to conserve biodiversity for its intrinsic value; protected areas with restricted access (Gasalla et al., 2022).	E.g.: instrumental values, where people conserve and value nature for a sustained flow of ecosystem services; protected areas with human access for recreational benefits and sustainable use (Gasalla et al., 2022).

Nature As Culture (NAC) perspective focuses on the co-conservation and co-management of biological and cultural diversity, across a wide range of interconnected bio-cultural systems. It values flagship species that are identified by local communities and indigenous people and can be called a reciprocal stewardship, where reciprocity and harmony drive the relationships of humans with nature at all levels of organisation (IPBES, 2023). The keywords used to summarize this future are biocultural heritage, cultural landscapes, self-sufficient settlements, engineered ecosystems, community-based management, one with nature, mother earth/cosmovision (IPBES, 2023).

Nature For Nature (NFN) perspective considers that people respect and value all life on Earth intrinsically, so keystone species are essential to preserve ecosystem integrity (IPBES, 2023). It's characterized by a sparingly use of the available land, as vast areas of land are strictly protected from human interventions, and people live in dense self-sustaining urban areas designed to minimise the role of humans in the biosphere (IPBES, 2023). The keywords that define this vision are blue-green infrastructure, protected area, large-scale ecological dynamics, self-sufficient settlements, strict nature protection, land sparing, rewilding, wilderness, and smart cities (IPBES, 2023).

Nature For Society (NFS) perspective focuses on instrumental values as in benefits that nature provides to people (i.e., supporting crop production, climate regulation), assuming a highly connected world, where knowledge and technology are shared to boost an efficient and sustainable use of nature's contributions to people, while still ensuring maintenance of the ecosystem functions that support them (IPBES, 2023). Some keywords that define this perspective are eco-efficiency, green growth, smart cities, urban-rural integration, land-sharing, optimised ecosystem services, engineered ecosystems, sustainable use, and management (IPBES, 2023).

The NFF scenarios aim to contribute to global sustainability with their three future perspectives (IPBES, 2022c). However, following one NFF perspective may imply trade-offs with the other two perspectives. Figure 1 is a representation of the Nature Futures Framework, which core values are the relationships between people and nature. Each of the three vertices depicts the desirable future for nature and people according to each perspective – NAC, NFN and NFS (IPBES, 2022b). Desirable and attainable futures might be in a middle position relative to each of the perspectives, and not on one of the vertices or even closer to one of them than the others (Figure 1), because they are place or context specific and dependent, subject to local cultures and values. Besides that, the human-nature relationships may be perceived in diverse ways, according to other knowledge systems and world views (right side of Figure 1) (IPBES, 2022a, 2022c).

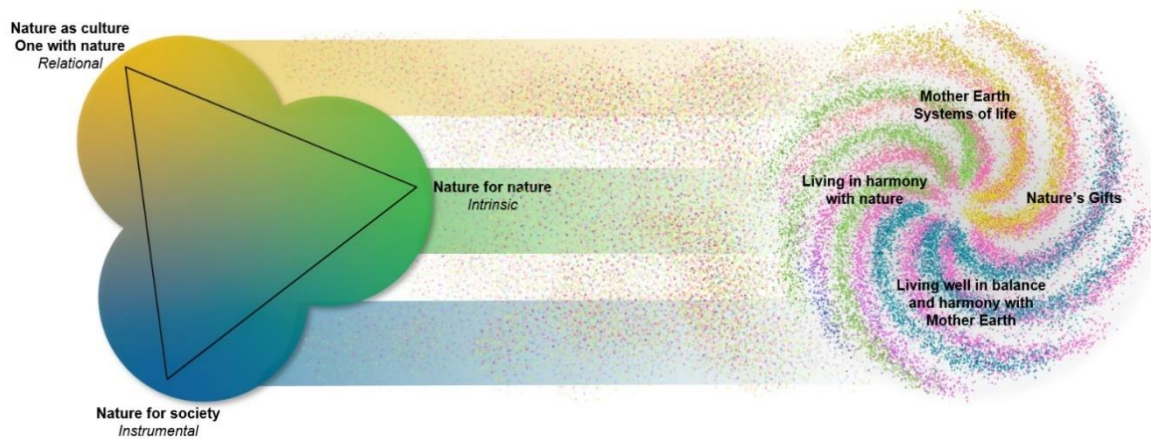


Figure 1 - Representation of the Nature Futures Framework, a flexible tool to support the development of scenarios and models of desirable futures for people, nature, and Earth (IPBES, 2022a) (ipbes.net)

The NFF has been used by Dou et al. (2023) to develop land systems scenarios for Europe, and projecting changes for 2050 following the three NFF scenarios. The NAC scenario favours land systems providing agricultural heritage features, the NFN favours land systems providing species conservation, and the NFS one focuses on land systems that provide climate regulation (Dou et al., 2023). Overall, the three scenarios align with the EU's Biodiversity Strategy for 2030, assuming gradual increases in the target objectives to the year 2050, and at the same time, ambitioning to increase, in the long term, the environmental protection and restoration (Dou et al., 2023).

The NFF is a novel and promising approach, which applied to research on land use or land systems change may contribute to increasing understanding on the current and future distribution of species under land systems change, namely species of conservation concern, to support the development and implementation of management for tailored conservation.

1.4. Research objectives and structure of the thesis

In this study we assess how environmental changes, specifically land systems change, may affect the future distributions of twelve species of conservation concern reported under Article 17 of the Habitats Directive for the Iberian Peninsula. Specifically, this research evaluated trends of the potential range of the targeted species (reflected as expansion or contraction), under scenarios of land system change and assessing such trends considering the location of the areas designated for nature conservation (i.e., Natura 2000 SACs) in the Iberian Peninsula.

This thesis is organized into four sections. The Introduction sets the state-of-the-art of the importance of the application of SDMs to species of conservation concern in the context of environmental change. In the second section (Methods), we describe the study area (Iberian Peninsula), the selection of targeted plant species and data gathering, the selection of environmental variables, and the overall analytical framework, including the modelling approach implemented and statistical analysis. In the third section, Results, we present the most important results, namely species range changes under scenarios of land system change (NAC, NFN and NFS), and assess such changes by IUCN category and within the Natura 2000 Network while considering spatial patterns. In the fourth section, Discussion, we discuss the major results, in the context of previous research, as well as synthesise the outcomes and present limitations of this study and perspectives for future research.

2. Methods

2.1. Study Area

The study-area, the continental area of the Iberian Peninsula (IP), is located at the most southwestern part of Europe and expands over an area of 583 000 km² (Figure 2) (Benito-Calvo et al., 2009). It includes Portugal and Spain and is bordered in the south and east by the Mediterranean Sea, in the north and west by the Atlantic Ocean, and by the Pyrenees in the northeast region (bounded from 9°32' to 3°20'E and 35°56' to 43°55'N). The IP has a particular set of characteristics, reflecting in a unique and heterogeneous climate, geology, and biodiversity throughout the territory (Martins et al., 2014; Mingarro & Lobo, 2021).



Figure 2 - Location of the study area, the Iberian Peninsula (Portugal and Spain) in the European Union (b). Special Areas of Conservation (SACs) integrating the Natura 2000 network in the study-area are also shown (a).

The orogeny is defined by large mountain ranges (e.g., *Cordillera Cantábrica*, in the north, and *Cordilleras Béticas* in the south of the IP), with a west-east orientation, and the centre of the Iberian Peninsula is dominated by two plateaus, *Meseta Norte* and *Meseta Central*. The largest plateau, *Meseta Central*, covers an area of over 210 000 km², with elevations ranging from 600 to 760 m. In the core of *Meseta Central* is located the *Sistema Central*, a group of mountain ranges, the highest ones designated *Serra da Estrela*, *Sierra de Guadarrama* and *Sierra de Gredos* (Fullea et al., 2021; Ribeiro et al.,

1990). The highest point of IP is Mount *Mulhacén* in *Serra Nevada*, with 3478 m. The western regions of the IP are characterized by acidic rocks, while basic rocks dominate the eastern half of the study-area. The major rivers run from east to west, and most of them drain directly to the Atlantic Ocean.

The IP exhibits a strong climatic gradient (Reino et al., 2018), with temperate zones with higher precipitation and low temperatures prevailing in the northwest, whilst areas in the southeast are drier and warmer. The dominant climate type is Mediterranean, leading to hot dry summers and mild wet winters but, with the proximity to the Atlantic, on the north and north-west areas the climate becomes more humid and milder, with higher precipitation in the winter months (Deus et al., 2022; Martins et al., 2014).

The combination of climatic and biophysical characteristics existent in the IP lead to a diverse mosaic of vegetation (e.g., scrub communities, oak, and pine forests), supporting the existence of a variety of taxonomic groups with diverse ecological needs (Molina-Venegas et al., 2013; Pascual et al., 2011; Regos et al., 2015). Because of this the Iberian Peninsula is one of the main hotspots of biodiversity in the Mediterranean basin, with high levels of plant diversity, namely endemism's (M. B. Araújo et al., 2007; Pascual et al., 2011).

The Iberian Peninsula has a vast system of areas designated for conservation, which includes 20% of the terrestrial surface of the Natura 2000 network in the EU (EEA, 2021a). At the Member State level, Portugal has 1 National Park (*Parque Nacional Peneda-Gerês*), 14 Natural Parks, 10 Natural Reserves and several Protected Landscapes and Natural Monuments. From a total of 414 areas, 247 Portuguese sites are designated under national laws and 167 are recognized as Natura 2000 sites, summing to 22,4% of land covered by all types of protected areas in this country (EEA, 2021b). Spain has 28% of its land designated for conservation, the second largest terrestrial network of protected areas in the EU (EEA, 2021b). This sums up 3705 areas, comprising 1847 sites designated under national laws and 1858 as Natura 2000 sites (EEA, 2021b). It has 16 National Parks, 53 Biosphere Reserves and various Natural Reserves, Monuments and Landscapes. In Figure 2, the Natura 2000 SACs are represented, as they are the protected areas considered in this study. While the Iberian Peninsula includes a vast network of protected areas, this research has particularly focused on the areas designated as Special Areas of Conservation (SACs, Figure 2), which are priority areas for monitoring and reporting under the Article 17 of the Habitats Directive (CBD, 1992; European Commission, 2021a).

2.2. Targeted species and occurrence data

Selection of targeted species started by a thorough screening of the plants reported by Portugal and Spain (or both) in the context of Article 17 of the EU Habitats Directive ([Council Directive 92/43/EEC](#)) (CBD, 1992). From the 344 plants reported in the Iberian Peninsula, 183 are reported by the Portuguese, 204 species by Spanish, while 37 are reported by both Conservation Authorities. The screening process included harmonization of names and synonyms of species under the Article 17 of the Habitats Directive following the nomenclature proposed in *Flora Iberica* (Castroviejo, 2012).

Species occurrences for each plant were gathered from official reporting datasets, namely: the Portuguese Article 17 report, for 2013-2018 ([Habitats Directive Report](#)); the Portuguese Report of plant species for the Sectorial Plan of Natura 2000 network ([Flora - PSRN2000](#)); the Portuguese Red List Report for Vascular Flora ([Lista Vermelha da Flora Vascular de Portugal Continental](#)); the Spanish Report of Distribution of Habitats of Community Interest from 2013-2018 ([Species Article 17 \(2013-2018\)](#)); confirmed and validated records available in the Anthos Project ([Anthos](#)) and Flora-On ([Flora-On](#)). BIOPOLIS databases were consulted and used as well. Due to its characteristic restrict geographic distribution, species endemic from the non-continental part of the Iberian Peninsula i.e., endemic plants from Azores, Madeira, Baleares Islands, Canarias, and other islands were *a priori* excluded. For the final set of 193 plants, available records were gathered in the 10x10 km EEA grid defined in the context of the Article 17 of the Habitats Directive (European Environment Agency, 2011). For this final set of plants, 71 were reported only by Portugal, 82 reported only by Spain and 40 species are reported by both countries.

For each plant reported in the IP, information regarding the reporting country (Portugal, Spain, or both) and to the country/region of origin of each species was collected. Additionally, information about the ecology of each species was collected, from a variety of sources, namely *Flora Iberica* (Castroviejo, 2012), *Flora-On*, International Union for Conservation of Nature (IUCN) (IUCN, 2022), European Nature Information System (EUNIS) (European Environment Agency, 2019), Global Biodiversity Information Facility (GBIF) (Global Biodiversity Information Facility, 2023) and the Spanish and Portuguese Red Lists (Carapeto et al., 2020; Saiz et al., 2019). Finally, the conservation status of each species according to the classification of the IUCN Red List of Threatened Species (IUCN, 2022) was collected, for the full range of species distribution (IUCN), and Portuguese (Carapeto et al., 2020) and Spanish (Saiz et al., 2019) territories. Five

categories characterizing species conservation status were considered: Least Concern (LC); Near Threatened (NT); Vulnerable (VU); Endangered (EN); Critically Endangered (CR). A taxon is included in the LC category if is widespread and abundant (and doesn't qualify for the other categories); NT if it doesn't qualify for the VU, EN or CR categories but is close to or is likely to qualify for a threatened category in the near future; VU when it's facing a high risk of extinction in the wild, and fits criteria such i.e., reduction in population size of $\geq 50\%$ over the last 10 years or three generations; EN if, based on the available information, meets the criteria of i.e., reduction in population size of $\geq 70\%$ over the last 10 years or three generations and therefore is facing a very high risk of extinction in the wild; and CR category, if the available information shows that it is facing an extremely high risk of extinction in the wild by meeting all the criteria (i.e., reduction in population size of $\geq 90\%$ over the last 10 years or three generations) (IUCN, 2012). In this research, grouping and analysis performed by IUCN category are based on the national classification, since reporting by each country reflects the most updated information.

After the initial screening step, a preliminary list of species and respective occurrences was obtained, i.e., locations where the species has been previously observed and reported. Such list was used, together with other additional information collected (i.e., conservation status, habitat characteristics and region or country of distribution) to select a set of twelve illustrative plants species to be modelled under the novel NFF scenarios of land systems change. Such species were selected according to the following criteria: (i) more than 30 reported occurrences; (ii) reported from PT, SP, or both (IP); (iii) conservation status and, (iv) reported habitats and ecology. Overall, the twelve illustrative species include the Least Concern (LC) category *D. pentaphyllum*, *G. nivalis*, *M. segetalis*, *T. capitellatus* and *X. vulgare*; the Vulnerable (VU) *N. cyclamineus*, *V. micrantha* and *V. cazorlensis*; the Near Threatened (NT) *E. nevadensis* and *J. valvatus*; the Endangered (EN) *A. baetica*, and the Critically Endangered (CR) *Rhaponticum exaltatum* (Table 2).

Table 2 – List and short characterization of the twelve (12) targeted species. Table includes the species name, abbreviation (first three letters of the name of the genus, plus the first three letters of the specific epitope). Characterization includes the Member State which is reporting each species in the context of Article 17, and conservation status for the Portuguese and Spanish territories (based on national Red Lists), and the general category considered by IUCN, as well as a short description of the species, habitats, number, and location of known and gathered occurrences and a representative image of each plant.

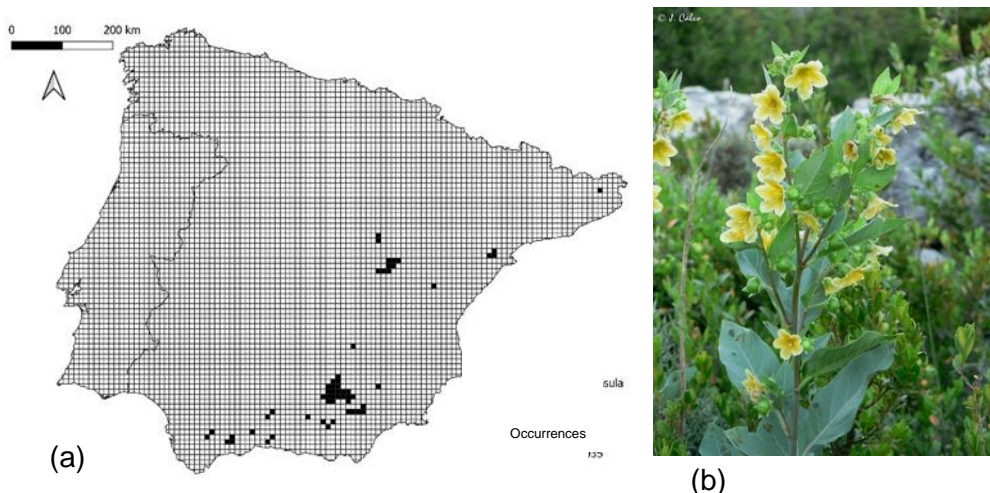
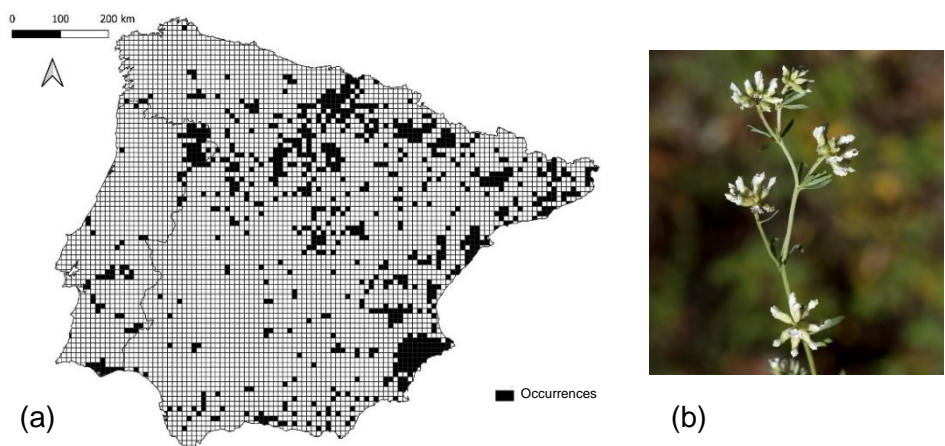
<i>Atropa baetica</i> Willk.			IUCN PT	IUCN SP	IUCN
ATRBAE	Reported by SP	57 Occurrences	-	EN	EN
<p><u>Ecology:</u> <i>Atropa baetica</i> is endemic to Spain, occasionally occurring in forest clearings, and in different communities generally composed of species from different succession stages, often on basic rather moist soils, on shady sites with open exposure (IUCN, 2022). ATRBAE is usually associated with areas under past and recent edaphic and anthropogenic disturbances (landslides, fires, decaying tree stumps, opening of tracks, logging roads), declining as the vegetation evolves towards stable and mature stages (Saiz et al., 2019).</p> <p><u>Distribution:</u> Centre-Eastern and South Spain <i>Almería</i>, <i>Córdoba</i>, <i>Cuenca</i>, <i>Granada</i>, <i>Guadalajara</i>, <i>Jaén</i>, <i>Málaga</i>, <i>Murcia</i> and <i>Tarragona</i>. It was reintroduced in <i>Albacete</i> and is extinct in <i>Cádiz</i> (Saiz et al., 2019).</p>		 <p>(a) Map of Spain showing the location of gathered occurrences for <i>A. baetica</i>. The map includes a grid, a scale bar (0, 100, 200 km), and a north arrow. Occurrences are marked with black dots and squares across the Iberian Peninsula. (b) Photograph of <i>Atropa baetica</i> flowers, showing yellow bell-shaped flowers on a green stem with large leaves.</p>			

Figure 3 – (a) Location of the gathered occurrences for *A. baetica*; (b) *Atropa Baetica* by J. Calvo (2008) (Anthos).

Main threats: Population fragmentation, herbivory and trampling by domestic (hunting) and wild ungulates, during fruiting (Saiz et al., 2019).

<i>Dorycnium pentaphyllum</i> Scop.			IUCN PT	IUCN SP	IUCN
DORPEN	Reported by PT	847 Occurrences	LC	-	DD
<p>Ecology: <i>Dorycnium pentaphyllum</i> occurs in clearings of low scrub, fallow land, roadsides, and slopes. It's an herbaceous plant or shrub, concentrated in areas of basic, dry, and stony soils (Carapeto et al., 2020; Porto, Araújo, et al., 2023).</p> <p>Distribution: In mainland Portugal has a large and dispersed area of distribution (about 84 600 km²) (Carapeto et al., 2020; Porto, Araújo, et al., 2023).</p> <p>Main Threats: No significant threats identified, therefore in the literature (Carapeto et al., 2020; Porto, Araújo, et al., 2023).</p>			 <p>Figure 4 - (a) Location of gathered occurrences for <i>D. pentaphyllum</i>; (b) <i>Dorycnium pentaphyllum</i> by Miguel Porto (Flora-on).</p>		
<i>Euphorbia nevadensis</i> Boiss. & Reut.			IUCN PT	IUCN SP	IUCN
EUPNEV	Reported by SP	175 Occurrences	-	NT	LC

Ecology: *Euphorbia nevadensis* prefers stony and rocky soils, mainly on acidic substrates. It occurs on sparsely vegetated land and grasslands, especially small cushion scrub and *salviares*, although it also occurs in thorny forest edges, under pine forests and mixed forests of various types (Saiz et al., 2019).

Distribution: Wide distribution, especially in the central and south-eastern mountain systems of the Iberian Peninsula: *Sistema Central*, *Sistema Ibérico*, *Sierras Setabenses* (*Aitana* and *Mariola*) and *Sierras Béticas* (*Sierra Nevada*, *Sierra of Baza*, *Sierra de María* and *Sierras Subéticas - Granada, Albacete, Murcia and Jaén*) (Saiz et al., 2019).

Main Threats: Has a broad distribution and it's threatened by abiotic, biotic, and anthropogenic factors (Saiz et al., 2019).

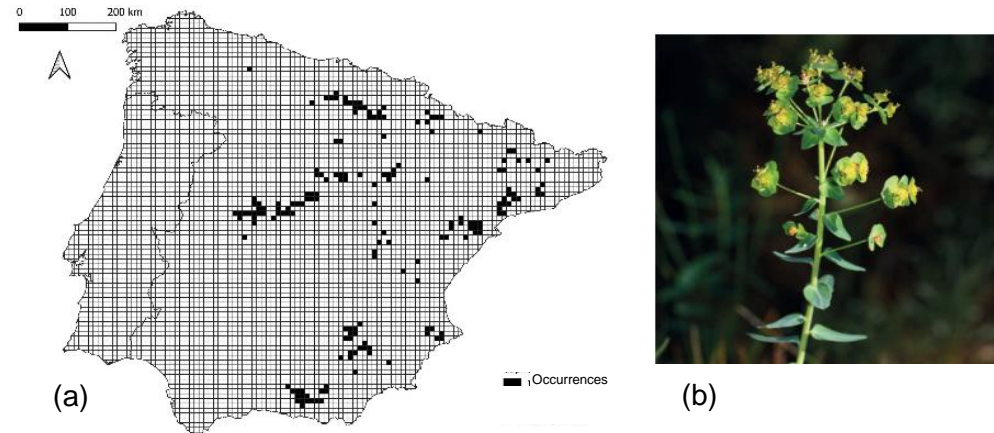


Figure 5 – (a) Location of gathered occurrences for *E. nevadensis*; (b) *Euphorbia nevadensis* by J.F. Jiménez Martínez (Atlas y Libro Rojo de la Flora Vasculare de España).

<i>Galanthus nivalis</i> L.				IUCN PT	IUCN SP	IUCN
GALNIV	Reported by SP	93 Occurrences	-	LC	NT	

Ecology: *Galanthus nivalis* occurs in beech forests, alder forests, *megaforbic* grasslands, rock shelves and alpine meadows, mainly in deep and moist soils. Temporary waterlogging of the soil that occurs with the thaw seems to favour *G. nivalis*, since good populations usually appear in watercourses (Saiz et al., 2019).

Distribution: It has a fragmented distribution and small populations, except for some very numerous ones in the *Pyrenees* and *Montseny* (Saiz et al., 2019).

Main Threats: The larger populations may be affected by forest exploration and livestock farming. Smaller and more isolated populations are threatened by low numbers of individuals, fragmentation, and a very restricted habitat (Saiz et al., 2019).

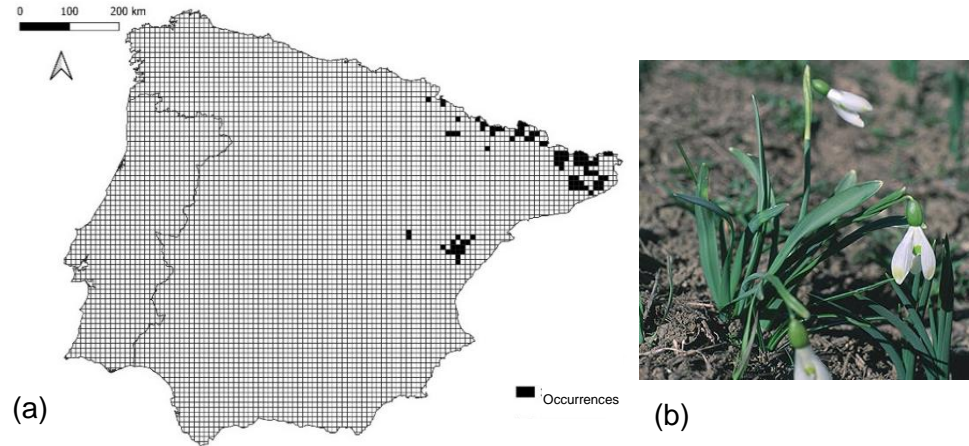


Figure 6 – (a) Location of gathered occurrences for *G. nivalis*; (b) *Galanthus nivalis* by A. Herrero, 2004 ([Anthos](#)).

<i>Juncus valvatus</i> Link.				IUCN PT	IUCN SP	IUCN
JUNVAL	Reported by PT	71 Occurrences		NT	-	VU

Ecology: *Juncus valvatus* is a geophyte endemic to Portugal. This species can be found in wet meadows, flooded depressions, banks of freshwaters of limestone and siliceous mountains, as well as other seasonally inundated areas, including roadsides (Carapeto et al., 2020).

Distribution: In Portugal, the populations are in the centre-east of the country, around Lisbon, from the *Saloia* region in the west to eastern *Ribatejo*, towards *Santarém* (Carapeto et al., 2020).

Main Threats: The major threats are the expansion of urbanized areas, the agricultural use of land and infrastructures (IUCN, 2022; Porto, Lemos, et al., 2023).

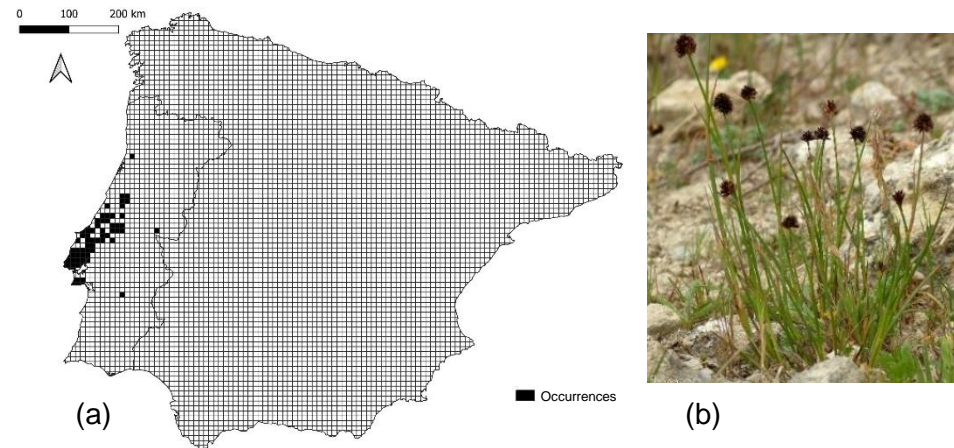


Figure 7 – (a) Location of gathered occurrences for *J. valvatus*; (b) *Juncus valvatus* by Miguel Porto ([Flora-on](#)).

<i>Melilotus segetalis</i> (Brot.) Ser.			IUCN PT	IUCN SP	IUCN
MELSEG	Reported by PT	67 Occurrences	LC	-	DD

Ecology: *Melilotus segetalis* is an annual sweet clover (therophyte) found in cultivated fields, fallow land, roadsides, mainly with nitrified soils, usually marly or clayey and sometimes somewhat saline (Carapeto et al., 2020, 2023).

Distribution: It's endemic to Portugal and there are some uncertainties about its distribution due to insufficient surveying. It's still relatively frequent around Lisbon, although some clusters may be the result of individuals escaped from former cultivation (Carapeto et al., 2020, 2023).

Main Threats: Main pressures include the use of chemicals in agriculture; removal of roadside trees and vegetation; and natural succession resulting in species composition change (other than by direct changes of agricultural or forestry practices) (Carapeto et al., 2020, 2023).

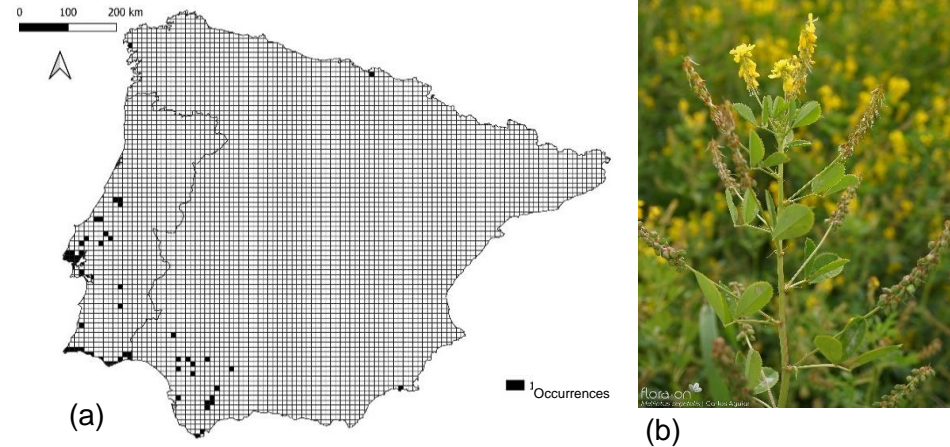


Figure 8 – (a) Location of gathered occurrences for *M. segetalis*; (b) *Melilotus segetalis* by Carlos Aguiar (Flora-on).

<i>Narcissus cyclamineus</i> DC.				IUCN PT	IUCN ES	IUCN
NARCYC	Reported by PT and SP	141 Occurrences		VU	-	LC

Ecology: *Narcissus cyclamineus* is an endemic plant (geophyte) from the Northwest of the Iberian Peninsula (*Galicia* and northern Portugal) (IUCN, 2022). Occurs in wet meadows and woodlands, often on the margins of water courses, and particularly in Portugal, can be found in the coastal mountains of the north of the country (Larrinaga et al., 2009).

Distribution: It has a reduced extent of occurrence and area of occupancy, as well as a small number of locations (P. V Araújo et al., 2023; Carapeto et al., 2020).

Main Threats: Major causes of destruction and degradation of this species habitat are human disturbances (recreational and leisure activities and infrastructure construction), the expansion of exotic species and the densification of scrubland (P. V Araújo et al., 2023; Carapeto et al., 2020).

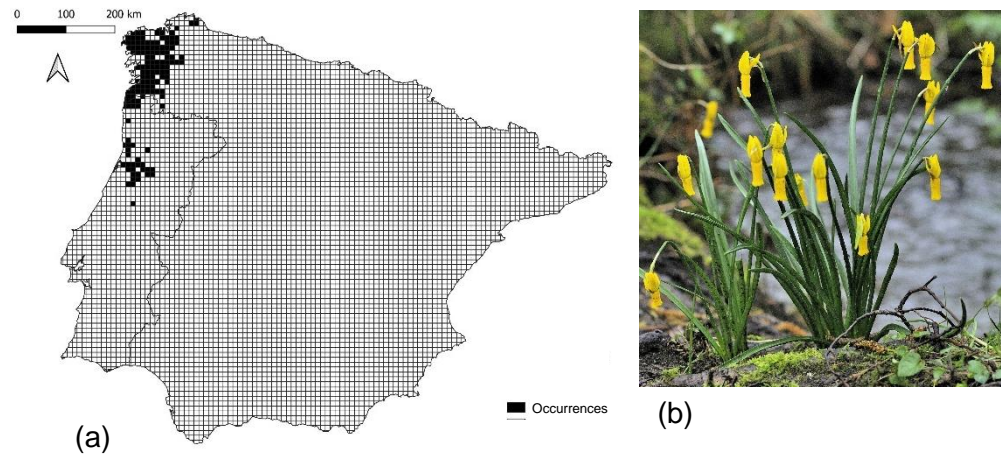


Figure 9 – (a) Location of gathered occurrences for *N. cyclamineus*; (b) *Narcissus cyclamineus* by Paulo Ventura Araújo (Flora-on).

<i>Rhaponticum exaltatum</i> (Cutanda ex Willk.) Greuter			IUCN PT	IUCN SP	IUCN
RHAEXA	Reported by PT and SP	38 Occurrences	CR	EN	NT

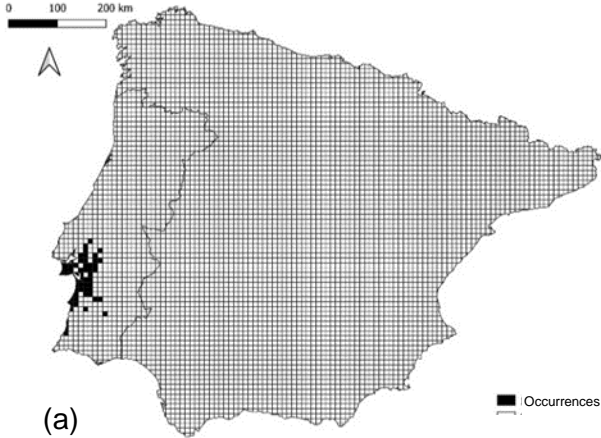

Ecology: *Rhaponticum exaltatum* is an Iberian endemic inhabiting sparse understories and clearings of oak forests and pine plantations, in mountainous areas on deep siliceous soils (Carapeto et al., 2020; Rodrigues et al., 2023; Saiz et al., 2019).

Distribution: Can be found in *Ávila, Salamanca, Zamora, Cáceres, Toledo* regions of Spain and *Trás-os-Montes* in Portugal. The Portuguese population is small and the disappearance of the plant from some historical occurrence sites is confirmed. In Spain, the species has eight subpopulations, being that one of them has 97% of the individuals, making it an important risk factor. In both countries, the populations have a very low extent of occurrence and area of occupancy (Carapeto et al., 2020; Saiz et al., 2019).

Main Threats: Conversion of woodland to forest plantations, abandonment of management practices in the woodland, forest fires and overgrazing (Carapeto et al., 2020; Rodrigues et al., 2023; Saiz et al., 2019).



Figure 10 – (a) Location of gathered occurrences for *R. exaltatum*; (b) *Rhaponticum exaltatum* -by Paulo Ventura Araújo ([Flora-on](#)).

<i>Thymus capitellatus</i> Hoffmanns. & Link				IUCN PT	IUCN SP	IUCN
THYCAP	Reported by PT	62 Occurrences		LC	-	NT
<p><u>Ecology</u>: <i>Thymus capitellatus</i> is an endemism from south-western Portugal found in sandy soils or stable marine dunes (Carapeto et al., 2020; Chozas et al., 2023).</p> <p><u>Distribution</u>: It has a small area of occupation, but populations consist of a large number of population centres and the number of mature individuals is estimated to be well over 15 000 (Carapeto et al., 2020; Chozas et al., 2023).</p> <p><u>Main Threats</u>: Urbanization, industrial development, agricultural intensification, and invasion by non-native species i.e., the replacement of maritime pine forests by stone pine or eucalyptus (Carapeto et al., 2020; Chozas et al., 2023).</p>						
<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;">  <p>(a)</p> </div> <div style="text-align: center;">  <p>(b)</p> </div> </div> <p>Figure 11 – (a) Location of gathered occurrences for <i>T. capitellatus</i>; (b) <i>Thymus capitellatus</i> by Ana Júlia Pereira (Flora-on).</p>						
<i>Veronica micrantha</i> Hoffmanns. & Link				IUCN PT	IUCN SP	IUCN
VERMIC	Reported by PT and SP	143 Occurrences		NT	VU	VU

Ecology: *Veronica micrantha* is endemic to the central and northwestern part of the Iberian Peninsula and occurs in deciduous forests and herbaceous communities of forest fringes preferring shaded stands with humid soils (Saiz et al., 2019).

Distribution: In Portugal is present in the regions *Minho, Trás-os-Montes, Beiras* and *Ribatejo*, and in Spain in the provinces of *Coruña, Lugo, Ourense, León, Zamora, Salamanca, Cáceres* and *Ávila* (Carapeto et al., 2020; Saiz et al., 2019).

Main Threats: Populations are severely fragmented and have a small occupation area. Threats include construction of dams (i.e., river *Tâmega*), installation of new forest stands, revitalization of agriculture and livestock intensification (P. V. Araújo et al., 2023; Carapeto et al., 2020; Saiz et al., 2019).

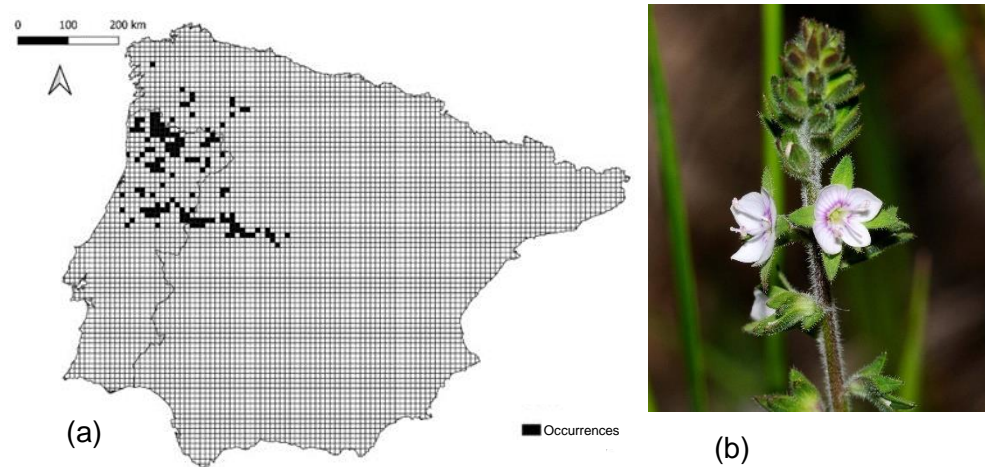


Figure 12 – (a) Location of gathered occurrences for *V. micrantha*; (b) *Veronica micrantha* by Paulo Ventura Araújo ([Flora-on](#))

<i>Viola cazorlensis</i> Gand.			IUCN PT	IUCN SP	IUCN
VIOCAZ	Reported by SP	37 Occurrences	-	VU	DD

Ecology: *Viola cazorlensis* grows on limestone rocks (Saiz et al., 2019).

Distribution: *Sierra de Cazorla, Segura and Las Villas*, Spain (Saiz et al., 2019).

Main Threats: Main pressures are abiotic processes (erosion, submersion, salinization) as well as anthropogenic ones (e.g., sports, tourism, roads, bridges and other infrastructures, intensive grazing or overgrazing by livestock, abstraction of surface and ground water for resource extraction) (Saiz et al., 2019).

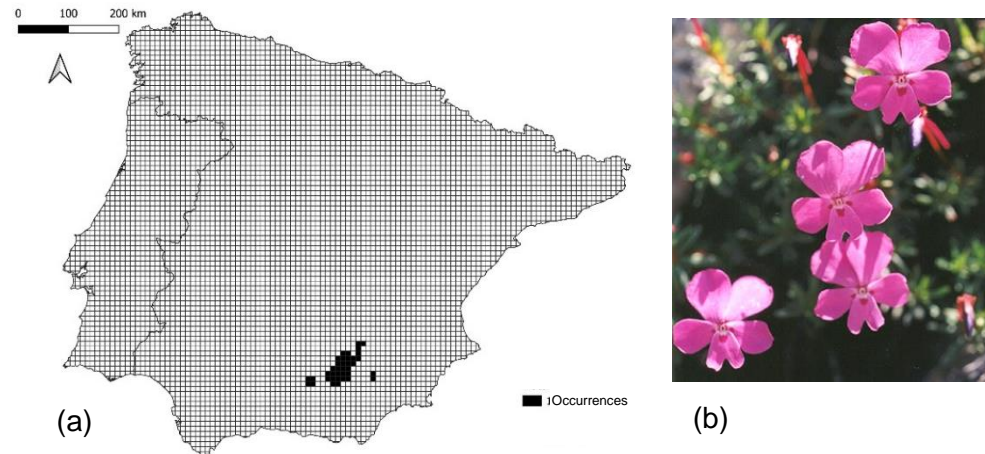


Figure 13 – (a) Location of gathered occurrences for *V. cazorlensis*; (b) *Viola cazorlensis* by Juan Real (2003) ([Anthos](#)).

***Xiphion vulgare* Mill.**

XIPVUL

Reported by PT and SP

283 Occurrences

IUCN PT	IUCN SP	IUCN
LC	LC	DD

Ecology: *Xiphion vulgare* is a geophyte endemic to the Iberian Peninsula, occurring in edges and clearings of scrub, scrubland or woodland, in crevices of rocky outcrops and on very stony soils (Carapeto et al., 2020; Porto, Pereira, et al., 2023; Saiz et al., 2019).

Distribution: It is known from the province of Extremadura in Spain and from central Portugal. The population trends are poorly known in both Portugal and Spain, but they are often small and fragmented (Carapeto et al., 2020; Saiz et al., 2019).

Main Threats: Expansion of invasive alien species, the establishment and management of eucalyptus stands and the construction of weirs and wind farms (Carapeto et al., 2020; Saiz et al., 2019; Silva et al., 2023).

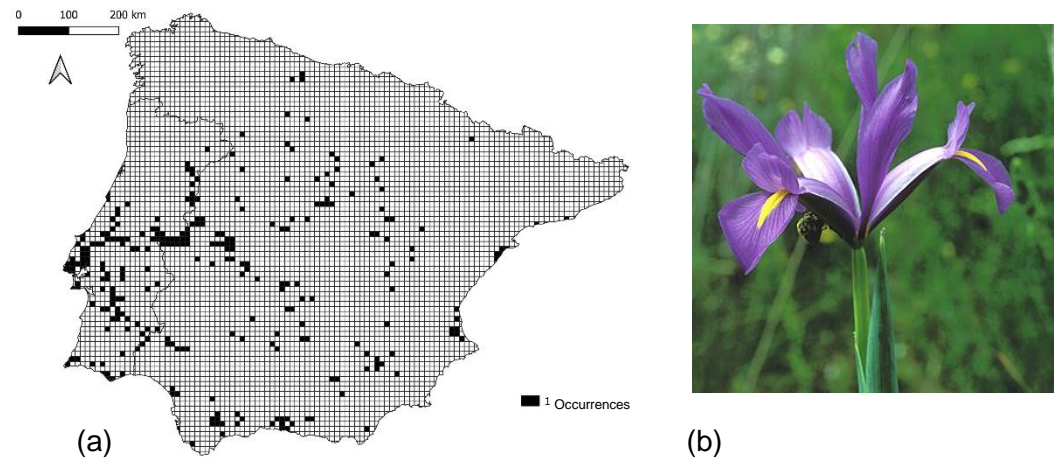


Figure 14 – (a) Location of gathered occurrences for *X. vulgare*; (b) *Xiphion vulgare* by A. Prunell ([Anthos](#)).

2.3. Environmental variables and scenarios of change

Three sets of environmental variables were considered to model the targeted species: climatic, topographic and land systems. All spatial information used was harmonized to match the EU 10x10 km EEA grid for the Iberian Peninsula, which includes 6078 grid cells. Six variables were used to feed models for each species considered, complying with the requirement of a minimum of five occurrence records per variable to avoid overfitting (Araujo et al., 2010; Proosdij et al., 2016).

Climatic and Topographic data

The bioclimatic data used was obtained from CHELSA - Climatologies at High Resolution for the Earth's Land Surface Areas - ([Chelsa Climate](#)) (Karger et al., 2017), consisting of layers of the monthly temperature, precipitation and various derived variables, for the years 1979-2013. Overall, bioclimatic data has been developed for species distribution modelling and related ecological applications. CHELSA includes nineteen bioclimatic variables, with a resolution of 1km², derived from monthly mean, max, mean temperature, and mean precipitation values, that can represent annual trends (mean annual temperature or annual precipitation), seasonality (annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month).

In a first step, bioclimatic layers were harmonized, from a spatial resolution point of view, with the article 17 EEA 10x10 km reporting grid (European Environment Agency, 2011). The harmonization, implemented in QGIS (QGIS, 2022), consisted in calculating the mean value of all 1km² pixels within each of the 10x10km grid, with the use of the Zonal Statistics Tool, for each of the nineteen available bioclimatic variables.

To derive variables reflecting topographic variation, we considered the Digital Elevation Model (DEM) for Europe (EU-DEM, version 1.0) from Copernicus Land Monitoring Service ([Copernicus](#)) (Copernicus, 2016). Overall, the DEM constitutes a digital surface model (DSM) representing the first surface as illuminated by the sensors, based on SRTM and ASTER GDEM data integrated through a weighted averaging approach, which results in a generated as a contiguous layer with a spatial resolution of 25m. We used the DEM to derive Hillshade, Slope, and Terrain Ruggedness Index (TRI) using QGIS (QGIS, 2022). To summarize, DEM represents the elevation of the terrain, Hillshade represents, as a 3D image, the terrain using light and shadow, and Slope

informs about how steep the terrain is. TRI expresses the amount of elevation difference between adjacent cells of a DEM. It calculates the difference in elevation values from a centre cell and the eight cells immediately surrounding it. Then it squares each of the eight elevation difference values to make them all positive, sums them, and takes the square root. To harmonize the spatial resolution of topographic variables with the EEA 10x10 km grid (European Environment Agency, 2011), Zonal Statistics from QGIS (QGIS, 2022) was used to calculate the value of each of the topographic variables for each grid cell.

Land Systems data

Land systems data (Dou, 2021), constitutes a high-resolution representation of European land systems, including important land use and landscape characteristics, on a 1 km² grid. Representing a spatially explicit baseline for the year of 2015, it includes twenty-five (25) land systems divided into four main categories, based on the prevailing land cover: settlements, forests, croplands, and grasslands. Each land system is subdivided into three (3) classes: low, medium, and high land use intensity. Moreover, this dataset includes mosaic systems, which while not dominated by a specific land type, integrate a variety of classes, such as forest/shrub mosaics or agricultural mosaics (Dou et al., 2021b). Land systems data for each of the 25 land systems present in the Iberian Peninsula, and respective intensity classes was expressed as the percentage of the area

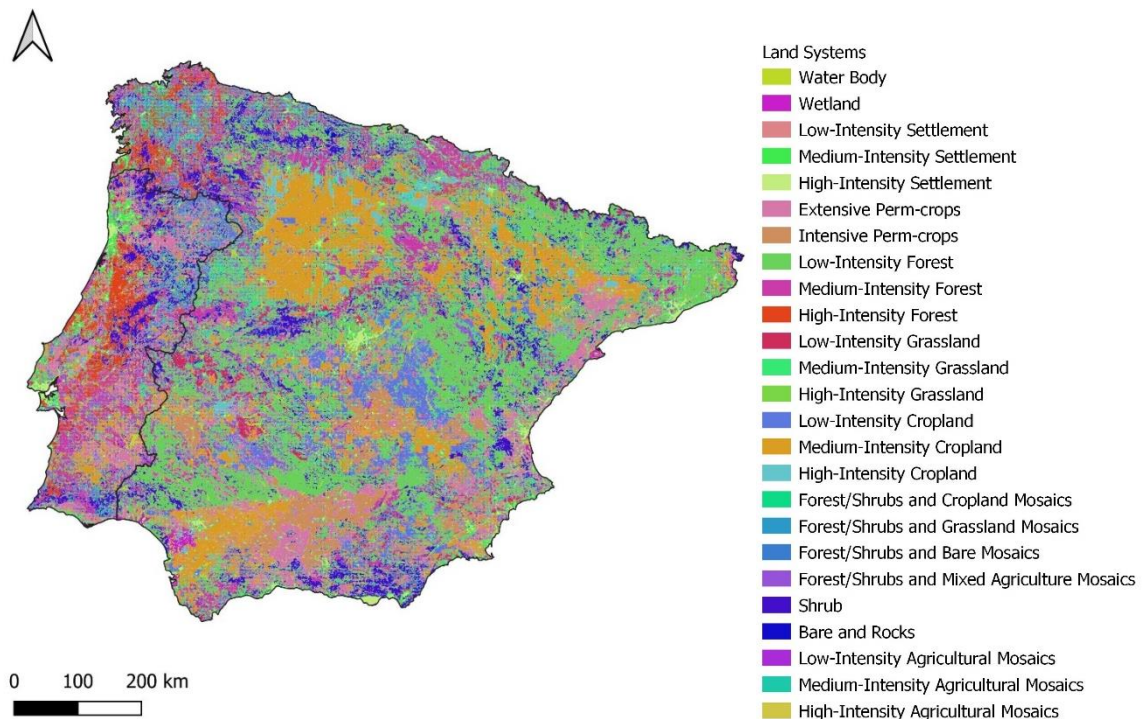


Figure 15 - Representation of the twenty five (25) Land Systems present across the Iberian Peninsula (Dou et al., 2021).

occupied by each within each cell of the EEA 10x10 km grid and can be seen on Figure 15.

Final set of variables

After harmonization of data, we calculated correlation, VIF (Variance Inflation Factor) and computed a PCA (Principal Component Analysis) using all variables available for the three sets (climatic, topographic and land systems) (for more detailed information see Supplementary Material - Appendix 1, Tables 11, 12 and 13) (Sillero et al., 2021). Within each set of environmental variables, we excluded those exhibiting correlation values > 0,80, and VIF > 10. From the legible variables, we selected two climatic variables - mean annual air temperature (bio1) and annual precipitation (bio12) - one topographic variable -Terrain Ruggedness Index (TRI) -, and three land systems related variables - forest/shrubs and cropland mosaics (LU71), forest/shrubs and grassland mosaics (LU72) and low-intensity agricultural mosaics (LU731). The final set of variables was tested also for correlation and VIF values (Tables 4 and 5). The final set of variables (Table 3) reflects a selection based on statistical criteria (threshold values for correlation = 0,70 and VIF = 10, and higher variability in the study area assessed through PCA) and ecological relevance of the variables.

Table 3 - Final set of environmental variables selected for modelling targeted species. variables designation, code utilized as abbreviation, the unit of measuring and meaning of each of the six selected environmental variables is presented.

Variables	Code	Unit	Meaning
Mean Annual Air Temperature	bio1	°C	Mean annual daily mean air temperatures averaged over 1 year
Annual Precipitation Amount	bio12	kg/m ²	Accumulated precipitation amount over 1 year
Terrain Ruggedness Index	TRI	km	Amount of elevation difference between adjacent cells of a DEM
Forest/Shrubs and Cropland Mosaics	LU71	%	Percentage of areas with small parcels of forest/shrubs and cropland, per grid cell
Forest/Shrubs and Grassland Mosaics	LU72	%	Percentage of the areas with small parcels of forest/shrubs and grassland, per grid cell

Low-intensity Agricultural Mosaics	LU731	%	Percentage of areas with low density of inorganic fertilizer input, small field size, and low livestock density, per grid cell
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Table 4 - Variance Inflation Factor (VIF) values for the selected variables.

Variables	VIF
bio1	1,61
bio12	1,35
TRI	1,97
LU71	1,17
LU72	1,24
LU731	1,09

Table 5 - Correlation values for the selected variables.

	bio1	bio12	TRI	LU71	LU72	LU731
bio1	1,00					
bio12	-0,32	1,00				
TRI	-0,56	0,47	1,00			
LU71	-0,12	0,11	-0,13	1,00		
LU72	-0,29	0,18	0,35	-0,21	1,00	
LU731	-0,02	-0,18	-0,19	0,03	0,07	1,00

Future Scenarios

Data reflecting land systems in 2050 were downloaded from Verburg (2023). Overall, this European dataset is available at a 1km² spatial resolution and reflects changes on land systems from the 2015 baseline (Dou (2021)) to 2050 for the three scenarios built according to each of the three Nature Futures Framework (NFF) storylines (Pereira et al., 2020; Verburg, 2023). The referred scenarios, reflecting alternative views for meeting the sustainability targets include: Nature as Culture (NAC) - favours the preservation of agricultural heritage features, highlights the relational value and the Nature-People relationship; Nature for Nature (NFN) – favours greater species conservation, highlights the intrinsic value of nature and preservation of Nature; and Nature for Society (NFS) – favours landscapes providing strong climate regulation, highlights the instrumental value of Nature and the use of Nature by People for their

benefit (Pereira et al., 2020; Verburg, 2023). For each of the three land systems considered (LU71, LU72 and LU731, Table 3), data for 2050 was expressed as the percentage of the area occupied by each within each cell of the EEA 10x10 km grid (European Environment Agency, 2011).

2.4. Modelling and data analysis

To address the impacts of environmental change in the targeted species distributions, we calibrated models with the selected climatic, topographic and land systems variables. Models were calibrated considering as baseline the reporting of 2013-2018 - current conditions -, and projected for 2050, considered the future, for the three available NFF scenarios (NAC, NFN, NFS). As described in Verburg (2023), the land systems projections for the NFF scenarios integrate changes in climate. Therefore, to avoid redundancy or potential duplication of climate change on targeted species future distributions, climate change scenarios were not individually considered in the scope of this study.

Model calibration and evaluation

Models were calibrated using the `biomod2` package (Thullier et al., 2021) implemented in R (R Development Core Team, 2022). All eleven (11) available modelling techniques in `biomod2` (ANN - Artificial Neural Network, CTA - Classification Tree Analysis, FDA - Flexible Discriminant Analysis, GAM - Generalized Additive Model, GBM - Generalized Boosting Model, GLM - Generalized Linear Model, MARS - Multiple Adaptive Regression Splines, MAXNET - Maximum Entropy, RF - Random Forest, SRE - Surface Range Envelop, XGBOOST - eXtreme Gradient Boosting Training) were implemented for each plant species using default parameters.

As only presence data was available, a set of pseudo-absences were randomly selected for each plant, by calculating three times the number of known occurrences for each species (as seen on Table 14 – Supplementary Material – Appendix 2), according to recommendations by Barbet-Massin et al., 2012 and `biomod2` developers ([biomod2 PseudoAbsences](#)). To account for uncertainty of pseudoabsence selection, ten (10) different sets of pseudo-absences were created (Barbet-Massin et al., 2012). A total of ten (10) replicates were used for each of the eleven (11) algorithms using 80% - 20% of presence data for training-testing each replicate (M. B. Araújo et al., 2011). Model accuracy was measured as the Area Under the Curve (AUC), because it takes into consideration the false-positive and the true-positive error rates and it's threshold-independent (Elith et al., 2006; Sillero et al., 2021, 2023). The values for AUC range between 0 and 1, where models assigned 0,5 have no predictive power and 1 represents a perfect model (Guisan et al., 2007). If the AUC values are lower than 0,5, the model is considered to have a predictive ability worse than expected by chance; lower than 0,7,

are seen as poorly accurate; between 0,7 and 0,9 the models are considered useful; higher than 0,9, the model is highly accurate (Guisan et al., 2007).

For each species, the resulting models were combined in an ensemble-forecasting framework (M. B. Araújo & New, 2007). The ensemble models were built by computing a consensus of single-model projections using a weighted average approach in which only models with an AUC > 0,7 were included (M. B. Araújo & New, 2007). This same AUC value was used to transform the projected occurrence probabilities into binary predictions per grid cell of the EEA 10x10 km grid (Elith et al., 2006).

Analysis of species distributions and dynamics

The models of the targeted SCC were calibrated for the Iberian Peninsula. Outcomes of models included the potential areas of distribution for the current conditions (2013–2017) and for the future (2050), for each of the three NFF scenarios (NAC, NFN and NFS) considered. Specifically, we obtained for each species: (i) the potential suitable habitat, reflected as the number of grid cells (of the EEA10x10 km grid) occupied by each species under current conditions; (ii) the future potential suitable habitat (in grid units) of each species projected according to scenarios of land system change (NAC, NFN and NFS); and, (iii) potential range change, which reflects the differences between species current and future potential habitat (i.e., the number of grid cells lost, gained and maintained in the future scenarios) (Figure 16).

Spatial analyses of modelling outcomes, i.e., the distribution of occurrences and of the potential area of distribution for the current and future conditions (for the three NFF scenarios), were implemented in QGIS (QGIS, 2022) (i.e., Figures i: xii – Supplementary Material – Appendix 4). Additionally, the percentage of area occupied in the Iberian Peninsula, by the species in each category (LC, VU, NT, EN and CR) was calculated. We also compared the species range change inside and outside of the Natura 2000 network SACs. We focus on SAC's (Figure 2) as they correspond to areas designated in the context of the Habitats Directive (CBD, 1992), thus relevant for the targeted species, reported under Article 17 (Council Directive 92/43/EEC). Natura 2000 SACs in the Iberian Peninsula covered 3535 cells of the EEA 10 x 10 km grid. Range changes of the targeted species under scenarios of change inside Natura 2000 SACs was also computed and reflected as the percentage of loss (number of grid units lost, divided by the total number of grid units inside the Natura 2000 Network) and gain (number of grid units gained, divided by the total number of grid units inside the Natura 2000 Network).

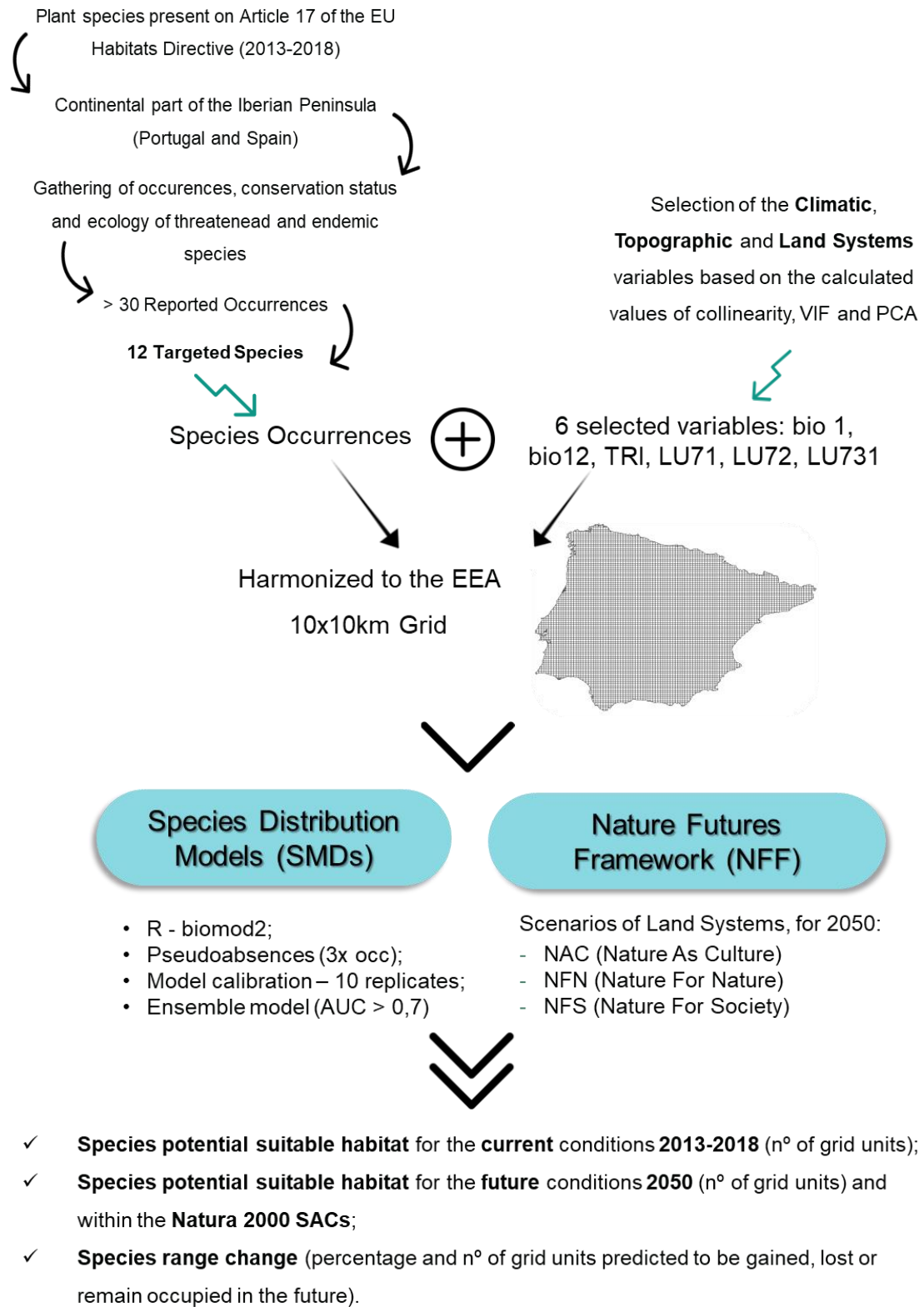


Figure 16 - Schematic representation of the the species and variables selection and the modelling process.

3. Results

This research assessed the potential impacts of land systems change on the distribution of twelve Iberian plants of conservation concern, by analysing changes in their ranges under future scenarios of change. We analysed the species potential distribution for the current conditions (i.e., reporting period of 2013-2017; section 3.1.) and compared it with the species potential distribution projected under the future NFF scenarios of change (2050). Results also reflect changes across species IUCN categories and within the Natura 2000 network sites (i.e. SAC's) (section 3.2.).

3.1. Assessing and understanding SCCs potential suitable habitat

Potential suitable habitat range for each of the targeted species was estimated based on outcomes from models calibrated for the Iberian Peninsula. Such outcomes were, in the first step, analysed against the known distribution of the targeted SCCs (i.e., occurrences, see section 2.2., Table 2), considering the current potential suitable habitat (section 6, Appendix 4 – Figures i: xii).

Overall, results show that the current potential suitable area for all targeted species is larger than the area depicted by the known records (Table 6; see more details in section 6 – Appendix 4 – Figures i: xii and Table 18). While most of the potential suitable habitat range was found to match the distribution of known occurrences, some differences were observed, namely: (1) an additional area located in the northeast of Portugal for *A. baetica*; (2) an expansion to the northwestern part of the IP (*Castilla*, *Galicia* and *Trás-os-Montes*) for *E. nevadensis*; (3) *G. nivalis* expands throughout the IP, especially in three big areas in the north, centre and south; (4) *J. valvatus* expands to the south part of Spain, and all throughout the coastline of Portugal; (5) an expansion along the south of Spain for *M. segetalis*; (6) for *R. exaltatum*, an expansion along the north, middle and south part of IP; (7) an expansion towards south and to the Spanish territory for *T. capitellatus*; (8) *V. micrantha* extends through all northern Portugal and to the northwest of Spain; and (9) an overall increase across Spain and in two areas of Portugal (one in the northern part, another in the southern part), for *V. cazorlensis*.

Table 6 - Overview of known records (occurrences) and potential suitable habitat (current conditions) for each of the twelve targeted species of conservation concern. These values (known records and potential suitable habitat) are expressed as number of grid cells for the Iberian Peninsula.

Species	Known records – Occurrences (grid units)	Potential suitable habitat – Current (grid units)
ATRBAE	57	687
DORPEN	847	1649
EUPNEV	175	1414
GALNIV	93	859
JUNVAL	71	742
MELSEG	67	1288
NARCYC	141	424
RHAEXA	38	693
THYCAP	62	417
VERMIC	143	1267
VIOCAZ	37	680
XIPVUL	283	1779

Outcomes from the ensemble modelling included values for the evaluation of ensemble models for each of the targeted species. Specifically, results depicted useful models for most of SCCs (AUC: 0.7-0.9; Appendix 3 - Table 17), and very good models (AUC > 0.9; Appendix 3 - Table 17) for *N. cyclamineus*, *T. capitellatus*, and *V. cazorlensis*. For detailed information on evaluation scores for each SCCs see Supplementary Material – Appendix 3, Tables 15 and 16 (before the ensemble procedure, including validation and calibration datasets, and after the ensemble procedure).

Table 7 summarizes the contribution of each environmental variable for each of the targeted SCCs. Overall, Mean Annual Air Temperature (bio1 - *T. capitellatus*: 0,73 ± 0,16; *M. segetalis*: 0,73 ± 0,15; *J. valvatus*: 0,49 ± 0,11; *E. nevadensis*: 0,47 ± 0,09; *G. nivalis*: 0,44 ± 0,13) and Annual Precipitation Amount (bio12 - *N. cyclamineus*: 0,87 ± 0,10; *V. micrantha*: 0,77 ± 0,11; *X. vulgare*: 0,62 ± 0,14; *D. pentaphyllum*: 0,52 ± 0,13; *J. valvatus*: 0,48 ± 0,15; *R. exaltatum*: 0,41 ± 0,22) were found to be the most relevant climatic variables in explaining most SCC distribution. Also, Terrain Ruggedness Index

(TRI) was found to be relevant in explaining the distribution of *A. baetica* ($0,64 \pm 0,17$), *V. cazorlensis* ($0,54 \pm 0,20$) and *E. nevadensis* ($0,41 \pm 0,10$) (Table 7).

Regarding the Land Systems variables, Forest/shrubs and grassland mosaics (LU72) were found to have a higher contribution in explaining *R. exaltatum* ($0,19 \pm 0,17$) and *J. valvatus* ($0,12 \pm 0,08$), while Forest/shrubs and cropland mosaics (LU71) had a higher contribution to explain *V. cazorlensis* ($0,14 \pm 0,13$) and *D. pentaphyllum* ($0,11 \pm 0,07$).

Table 7 – Variable importance for the twelve targeted plant species: bio1- Mean Annual Air Temperature; bio12 - Annual Precipitation; TRI - Terrain Roughness Index; LU71 - Forest/shrubs and cropland mosaics; LU72 - Forest/shrubs and grassland mosaics; LU731 - Low-intensity agricultural mosaics. Higher values are presented as bold. Values are presented as mean \pm standard deviation (SD). ATRBAE: *A. baetica*; DORPEN: *D. pentaphyllum*; EUPNEV: *E. nevadensis*; GALNIV: *G. nivallis*; JUNVAL: *J. valvatus*; MELSEG: *M. segetalis*; NARCYC: *N. cyclamineus*; RHAEXA: *R. exaltatum*; THYCAP: *T. capitellatus*; VERMIC: *V. micrantha*; VIOCAZ: *V. cazorlensis*; and XIPVUL: *X. vulgare*.

	bio1	bio12	TRI	LU71	LU72	LU731
ATRBAE	0,18 \pm 0,12	0,32 \pm 0,12	0,64 \pm 0,17	0,07 \pm 0,08	0,05 \pm 0,07	0,05 \pm 0,07
DORPEN	0,35 \pm 0,11	0,52 \pm 0,13	0,26 \pm 0,07	0,11 \pm 0,07	0,07 \pm 0,05	0,04 \pm 0,04
EUPNEV	0,47 \pm 0,09	0,26 \pm 0,08	0,41 \pm 0,10	0,04 \pm 0,05	0,03 \pm 0,03	0,02 \pm 0,03
GALNIV	0,44 \pm 0,13	0,18 \pm 0,12	0,39 \pm 0,14	0,04 \pm 0,05	0,04 \pm 0,04	0,04 \pm 0,05
JUNVAL	0,49 \pm 0,11	0,48 \pm 0,15	0,07 \pm 0,09	0,03 \pm 0,05	0,12 \pm 0,08	0,02 \pm 0,03
MELSEG	0,73 \pm 0,15	0,36 \pm 0,12	0,07 \pm 0,08	0,03 \pm 0,06	0,04 \pm 0,05	0,02 \pm 0,03
NARCYC	0,08 \pm 0,10	0,87 \pm 0,10	0,07 \pm 0,08	0,01 \pm 0,02	0,07 \pm 0,05	0,02 \pm 0,03
RHAEXA	0,23 \pm 0,19	0,41 \pm 0,22	0,17 \pm 0,17	0,12 \pm 0,13	0,19 \pm 0,17	0,03 \pm 0,06
THYCAP	0,73 \pm 0,16	0,18 \pm 0,16	0,13 \pm 0,13	0,04 \pm 0,05	0,04 \pm 0,07	0,02 \pm 0,04
VERMIC	0,20 \pm 0,10	0,77 \pm 0,11	0,07 \pm 0,05	0,02 \pm 0,03	0,03 \pm 0,03	0,02 \pm 0,02
VIOCAZ	0,15 \pm 0,15	0,33 \pm 0,15	0,54 \pm 0,20	0,14 \pm 0,13	0,04 \pm 0,06	0,04 \pm 0,05
XIPVUL	0,27 \pm 0,15	0,62 \pm 0,14	0,07 \pm 0,07	0,09 \pm 0,06	0,04 \pm 0,04	0,03 \pm 0,04

3.2. Forecasting changes in the distribution of SCCs under scenarios of change

Range size and changes across scenarios of land systems change

As shown on Figure 17, *X. vulgare* is predicted to occupy the largest area of all study species, with 1707 grid units for NAC, 1787 grid units for NFN, and 1571 grid units for NFS, followed by *E. nevadensis* (NAC: 1354; NFN: 1359; NFS: 1376), *D. pentaphyllum* (NAC: 1416, NFN: 1447; NFS: 1429), *V. micrantha* (NAC: 1267; NFN: 1253; NFS: 1253) and *M. segetalis* (NAC: 1153; NFN: 1173; NFS: 1165). All remaining SCCs have a range size lower than 820 grid units, with the smallest range being *T. capitellatus* (NAC:397; NFN: 394; NFS: 394) (see more details on Supplementary Material – Appendix 4, Tables ix:xi).

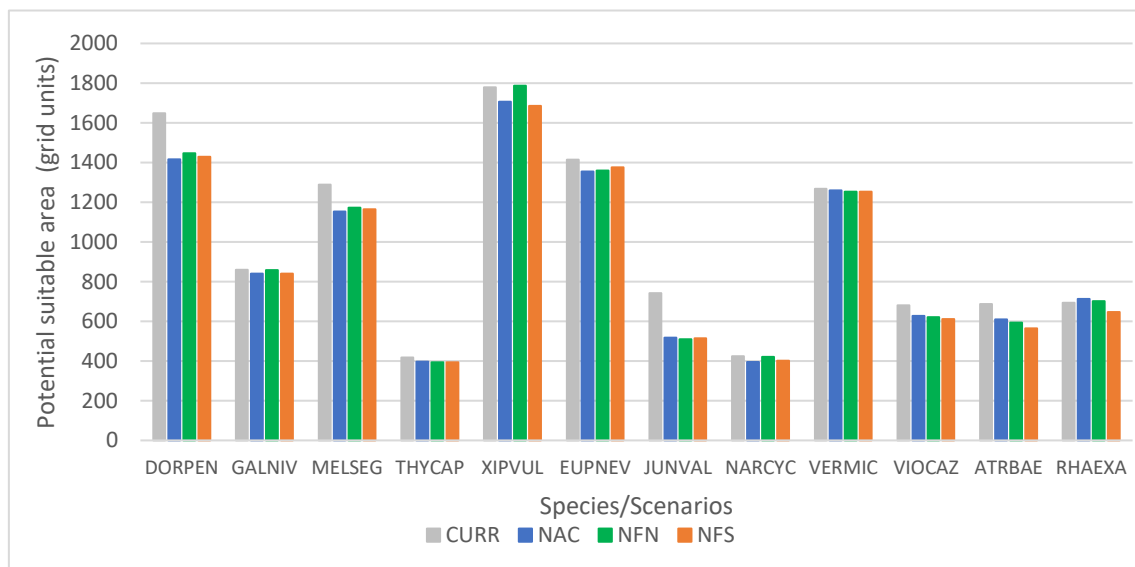


Figure 17 - Overview of the Current Range Size (CURR) and the Future Range Size), expressed as number of grid units, for the three Nature Futures Framework scenarios (NAC: Nature As Culture; NFN: Nature For Nature; and NFS: Nature For Society) for the twelve targeted species (ATRBAE *Atropa baetica*; DORPEN: *Dorycnium pentaphyllum*; EUPNEV: *Euphorbia nevadensis*; GALNIV: *Galanthus nivalis*; JUNVAL: *Juncus valvatus*; MELSEG: *Melilotus segetalis*; NARCYC: *Narcissus cyclamineus*; RHAEXA: *Rhaponticum exaltatum*; THYCAP: *Thymus capitellatus*; VERMIC: *Veronica micrantha*; VIOCAZ: *Viola cazorlensis*; and XIPVUL: *Xiphion vulgare*).

Considering the mean values for each scenario (i.e., considering the average values of the twelve SCCs for each scenario, Supplementary Material – Appendix 4 - Tables ix:xi), the percentage of gain varies between 3,17% (NAC) and 4,40% (NFS), the percentage of loss varies between 10,91% (NFN) and 13,56% (NFS), and the percentage of range change between -9,15% (NFS) and -7,03% (NFN). The mean Future range size for NAC is 915,75 grid units, for NFN 926,50 grid units and for NFS 907,00 grid units.

A pattern of decreasing range size, i.e. decreasing values of potential suitable area, was observed for most species and scenarios (Figure 17), reflected as negative values of percentage of range change (c.f. Table 8). *Juncus valvatus* was the species exhibiting highest range contraction under the three scenarios of land system change (NAC: -30,19%; NFN: -31,27%; NFS: -30,59%), followed by *A. baetica* (NAC: -11,35%, NFN: -13,68%; NFS: -17,90%), and *D. pentaphyllum* (NAC: -14,13%, NFN: -12,25%; NFS: -13,34%) (Table 8). All other species (*E. nevadensis*, *G. nivalis*, *J. valvatus*, *M. segetalis*, *N. cyclamineus*, *T. capitellatus*, *V. micrantha*, *V. cazortensis* and *X. vulgare*) have a range change lower than -10%, but of those species, the ones with lower negative values of range change are *E. nevadensis* (NFS: -2,69%), *G. nivalis* (NAC: -2,10%; NFN: -0,12%; NFS: -2,10%), *N. cyclamineus* (NFN: -0,71%), and *V. micrantha* (NAC: -0,63%; NFN: -1,10%; NFS: -1,10%). Conversely, positive values for range change, were observed for *R. exaltatum*, for the NAC and NFN scenarios (2,89% and 1,30%, respectively), and *X. vulgare*, for the NFN scenario (0,45%) (see also Table 8, more details in Supplementary Material - Appendix 4 – Figures xiii: xv).

3.3. Assessing species range changes across IUCN categories

Across IUCN categories, a general trend for decline of range (as seen in the previous section and on the values of range change of Table 8) was observed for Vulnerable (VU), Near Threatened (NT) and Least Concern (LC) species, meaning their future potential suitable area is expected to contract under all scenarios of change considered. The only exception to this is *X. vulgare* (XIPVUL) for the NFN scenario, resulting on a potential

Table 8 – Representation of the Species Range Change, expressed as percentage (%), for the twelve study species across the three scenarios considered - NAC, NFN and NFS. Values highlighted as bold format are the most relevant for each species. Columns depict changes for each scenario, with negative values of range change represented in red and below the axis, and positive values represented as green columns above the axis.

IUCN	Species Range Change (%)	NAC	NFN	NFS	NAC	NFN	NFS
LC	DORPEN	-14,13	-12,25	-13,34			
	GALNIV	-2,10	-0,12	-2,10			
	MELSEG	-10,48	-8,93	-9,55			
	THYCAP	-4,80	-5,52	-5,52			
	XIPVUL	-4,05	0,45	-5,23			
NT	EUPNEV	-4,24	-3,89	-2,69			
	JUNVAL	-30,19	-31,27	-30,59			
VU	NARCYC	-6,84	-0,71	-5,19			
	VERMIC	-0,63	-1,10	-1,10			
	VIOCAZ	-7,79	-8,68	-10,00			
EN	ATRBAE	-11,35	-13,68	-17,90			
CR	RHAEXA	2,89	1,30	-6,64			

expansion of the future range of this species. The Endangered (EN) and Critical (CR) categories represented only by *A. baetica* and *R. exaltatum*, respectively, showed contrasting trends, with *A. baetica* expected to decline in the future and *R. exaltatum* expected to expand its potential range under the NAC and NFN scenarios.

As seen on Table 9, when considering the percentage of area occupied by each IUCN category in the Iberian Peninsula, for the Least Concern (LC) the mean values of area occupied for each of the five species ranged between 6,50% to 28,41%. In the case of Vulnerable species, the values varied between 6,68% and 20,65%. The NT category ranged between 8,47% and 22,43%. Within the LC, NT and VU groups, a wider variation of the area occupied by each species was observed. Endangered and Critically Endangered species, with 9,69% and 11,31%, respectively, are expected to occur in smaller areas of the Iberian Peninsula in the future.

Table 9 - Percentage of area of the Iberian Peninsula (reflected as the percentage of grid cells occupied by each of the study species in the future), for the targeted species by IUCN category (LC, VU, NT, EN, CR). Mean values calculated using the values obtained for the three scenarios considered.

		NAC	NFN	NFS	Mean
LC	DORPEN	23,30	23,81	23,51	23,54
	GALNIV	13,84	14,12	13,84	13,93
	MELSEG	18,97	19,30	19,17	19,15
	THYCAP	6,53	6,48	6,48	6,50
	XIPVUL	28,08	29,40	27,74	28,41
NT	EUPNEV	22,28	22,36	22,64	22,43
	JUNVAL	8,52	8,39	8,47	8,46
VU	NARCYC	6,50	6,93	6,61	6,68
	VERMIC	20,71	20,62	20,62	20,65
	VIOCAZ	10,32	10,22	10,07	10,20
EN	ATRBAE	10,02	9,76	9,28	9,69
CR	RHAEXA	11,73	11,55	10,64	11,31

3.4. Assessing the impact of range changes in Natura 2000 network

Overall, the potential area occupied by the species inside the Natura 2000 SAC's (depicted by the number of grid units), corresponds to a fraction of the potential area determined for the Iberian Peninsula (Table 10 and Figure 18). Trends observed for SCCs potential suitable area within IP SACs relate with the trends observed for the whole IP (Figures 17 and 18), i.e. a trend for decrease of the potential suitable area, reflected as higher grid units to be lost (larger than the number of grid units to remain occupied or to be gained) (Table 10). Still, no relevant differences were found between results obtained for the three scenarios of land system change considered (Table 10 and Figure 18).

Table 10 – Range changes observed within the Natura 2000 protected SAC's for the twelve study species across the three scenarios considered, expressed as number of grid units, as well as the number of grid units predicted to be lost and gained, the percentage (%) of Range Change (percentage of gain minus the percentage of loss) and the general trend within the protected areas (decrease or increase). Mean values for each scenario are also presented. Relevant values are highlighted as bold format. (DORPEN: *D. pentaphyllum*; GALNIV: *G. nivalis*; MELSEG: *M. segetalis*; THYCAP: *T. capitellatus*; XIPVUL: *X. vulgare*; NARCYC: *N. cyclamineus*; VERMIC, *V. micrantha*; VIOCAZ: *V. cazorlensis*; EUPNEV: *E. nevadensis*; JUNVAL: *J. valvatus*; ATROBAE: *A. baetica*; and RHAEXA: *R. exaltatum*).

		Potential Suitable Area (grid units)			Gain (grid units)			Loss (grid units)			Range Change (%)			General trends		
		NAC	NFN	NFS	NAC	NFN	NFS	NAC	NFN	NFS	NAC	NFN	NFS	NAC	NFN	NFS
L C	DORPEN	876	882	870	57	79	105	-215	-231	-269	-4,47	-4,30	-4,64	↓	↓	↓
	GALNIV	550	561	552	21	31	29	-28	-27	-34	-0,20	0,11	-0,14	↓	↑	↓
	MELSEG	640	650	643	5	8	6	-61	-54	-59	-1,58	-1,30	-1,50	↓	↓	↓
	THYCAP	182	181	182	12	14	15	-18	-21	-21	-0,17	-0,20	-0,17	↓	↓	↓
	XIPVUL	898	954	886	45	70	57	-98	-67	-122	-1,50	0,08	-1,84	↓	↑	↓
N T	EUPNEV	843	843	854	17	17	34	-53	-53	-59	-1,02	-1,02	-0,71	↓	↓	↓
	JUNVAL	264	262	267	0	1	0	-121	-124	-118	-3,42	-3,48	-3,34	↓	↓	↓
V U	NARCYC	259	267	277	1	1	1	-23	-15	-5	-0,62	-0,40	-0,11	↓	↓	↓
	VERMIC	858	851	854	13	8	12	-19	-21	-22	-0,17	-0,37	-0,28	↓	↓	↓
	VIOCAZ	363	360	346	10	11	34	-41	-45	-82	-0,88	-0,96	-1,36	↓	↓	↓
E N C R	ATRBAE	347	339	321	1	1	5	-50	-58	-80	-1,39	-1,61	-2,12	↓	↓	↓
RHAEXA	469	455	418	38	33	23	-29	-38	-65	0,25	-0,14	-1,19	↑	↓	↓	
mean		546	550	539	18	23	27	-63	-63	-78	-1,26	-1,13	-1,45			

Analysis performed for the Natura 2000 SACs considering IUCN categories, disclosed a general trend of decline for all categories, even though variation was observed between plants in the same category, and across categories (Table 10). Results obtained for the

Natura 2000 SACs depict similar trends as to those obtained for the targeted species when considering the whole IP (Figure 18), except for *G. nivallis*, which showed a positive range change for the NFN scenario, and *R. exaltatum*, which showed a negative range change for the NFN scenario. Besides those exceptions, the rest of the species exhibit negative values of Range Change (percentage of Gain minus the percentage of Loss), since species are predicted to lose more grid units than they are expected to gain within the Natura 2000 SAC's. The only species that doesn't gain grid units within the SACs is *J. valvatus*, for NAC and NFS scenarios (Table 10). Considering the percentage of Range Change within the Natura 2000 Network, *D. pentaphyllum* has the highest value of loss inside Natura 2000 (NAC: -4,47%; NFN: -4,30%; and NFS: -4,64%), followed by *J. valvatus* (NAC: -3,42%; NFN: -3,48%; and NFS: -3,34%). On the other hand, *G. nivallis* (NFN: 0,11%), *X. vulgare* (NFN: 0,08%) and *R. exaltatum* (NAC: 0,25%) showed positive values of range change for specific scenarios. *X. vulgare* was found to exhibit the most relevant difference between scenarios (1,92% of change between NFS and NFN), followed by *R. exaltatum*, with 1,44% of change between NAC and NFS. Regarding IUCN categories, species in the Least Concern category presented the lowest values for the NFN scenario (with the exception of *T. capitellatus*); Vulnerable species were found to exhibit a percentage of change lower than 1,40%; the Near Threatened category has the lowest levels of range change for the NFS scenario; and the Critically Endangered and Endangered species follow a similar pattern, with values of range change for NFS higher than NFN, and both higher than NAC (Table 10).

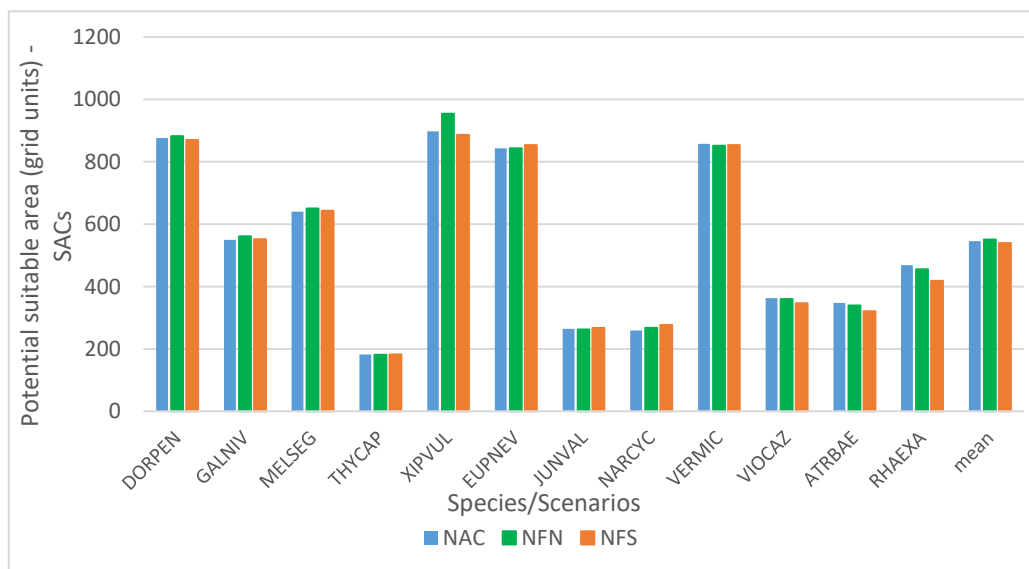


Figure 18 - Potential Suitable Area predicted to be occupied, in grid units, for the twelve study species and three NFF scenarios, within the Natura 2000 Network SAC's. The species are also in order of IUCN categories: Least Concern (*D. pentaphyllum*, *G. nivalis*, *M. segetalis*, *T. capitellatus*, *X. vulgare*); Vulnerable (*N. cyclamineus*, *V. micrantha*, *V. cazorlensis*); Near Threatened (*E. nevadensis*, *J. valvatus*); Endangered (*A. baetica*); Critically endangered (*R. exaltatum*).

4. Discussion

Assessing the effects of environmental change on the current and future distributions of species of conservation concern (SCCs) is essential to anticipate potential impacts that such changes may have on species of conservation concern and their habitats. While it is expected that changes in SCCs range occur as a response to climate and land use changes, accurately predicting such responses under contrasting scenarios of change is key to anticipate and prevent detrimental impacts and to support the design of tailored conservation (Alves et al., 2019; Boulangeat et al., 2014; Long et al., 2021; Nadeau et al., 2017; Oliver & Morecroft, 2014; Prakash & Verma, 2022; Sousa-Silva et al., 2014). However, while climatic data, namely future scenarios, have been widely used due to recognized high spatial and temporal resolutions, data with similar resolutions reflecting land use and respective scenarios of change is limited and characterized by low thematic and spatial resolutions (Dou et al., 2021b).

Recent research has focus on land systems data development as tools to improve information available for ecological research, namely species distribution assessments and monitoring (Dou et al., 2021b). Besides developing land systems data, Dou et al. (2021b) calibrated SDMs integrating land systems data with climate information, resulting in an increased performance of models for birds in comparison with models calibrated with land cover information or climate only (Dou et al., 2021b). Still, no research has yet used such data to analyse the impacts of land systems change on plant species of conservation concern.

This study is among the first to use land systems data and respective future scenarios, built on the Nature Futures Framework (NFF), to assess how changes will impact SCCs, thus contributing to advance the existing information available for monitoring and reporting purposes, as well as for new management and conservation actions. Accordingly, NFF scenarios, a novel view of potential futures recognizing the multiple values of nature, were applied determine potential impacts of change on twelve plant species of conservation concern future distributions in the Iberian Peninsula, including an assessment on trends for the potential habitat considering the location of areas designated for nature conservation (Natura 2000 SACs).

4.1. Assessing and understanding the distribution of SCCs potential suitable habitat

Overall, results depicted a potential suitable area for the current conditions larger than the area corresponding to confirmed occurrences (section 3.1.). While resulting distribution patterns for some species closely follow known occurrences e.g., *D. pentaphyllum*, *N. cyclamineus* and *X. vulgare*, they also allowed to identify other areas of potential suitable habitat for other SCCs.

Regarding the evaluation of the models (Supplementary Material – Appendix 3, Table 17), AUC values ranged between 0,7 and 0,9, corresponding to useful and good models. Moreover, results showed a more significant contribution of climate variables for the SCCs considered, since the climate gradient in the Iberian Peninsula is stronger than the topographic or land systems gradients (Table 7, section 3.1.) (Reino et al., 2018). The prevalence of climate over topographic and/or land systems can be observed for species such as *D. pentaphyllum*, *E. nevadensis*, *G. nivallis*, *J. valvatus*, *M. segetalis*, *N. cyclamineus*, *T. capitellatus*, *V. micrantha* and *X. vulgare* (c.f. Table 7, section 3.1.). Conversely, *A. baetica* and *V. cazortensis* were found to be the only SCCs where the topography information prevailed over climate and land systems.

4.2. Forecasting changes in the distribution of SCCs under scenarios of change

Range size and changes across scenarios of land systems change

Results show that, under the NFF scenarios considered, almost all targeted species lose potential area of suitable habitat by 2050. In fact, results (c.f. Figure 17 and Table 8 - section 3.2.) show that all plants (except for *R. exaltatum* and *X. vulgare*) will contract their habitat range under the three scenarios considered. More specifically, the Nature For Nature scenario (NFN) showed higher values for future species range size, lower values of range change and lower percentage of loss, since this is the most positive and nature focused of the NFF scenarios. While the NFS scenario resulted in higher values of percentage of gains (4,40%), it also showed higher values of percentage of loss (and smallest future range size), and consequently, the lowest values of range change of the three scenarios. Overall, our results are in agreement with recent research that analyses the impacts of climate and land use change on future species distributions (Alves et al., 2019; Boulangeat et al., 2014; Buse et al., 2015; García-Valdés et al., 2015; Sousa-Silva et al., 2014; Zhang et al., 2017). Sousa-Silva et al. (2014) reported a potential decrease in the species range size of 15% by 2050, due to climate and land use changes. In line with such results, our results highlighted that *V. micrantha* may lose 0,63% of its potential suitable habitat for NAC and lose 1,10 % for the NFN and NFS scenarios. In a study including *J. valvatus*, *N. cyclamineus*, *T. capitellatus* and *V. micrantha*, Alves et al. (2019) addressed the potential effects of climate and land use changes on the future distribution of the species under contrasting scenarios of change. While our results point to the future decrease on all four species range (reflected as negative values of range change) under the three NFF scenarios of change, Alves et al. (2019) reported punctual expansions for *J. valvatus*, *N. cyclamineus* and *T. capitellatus*, and contraction of *V. micrantha*. On the other hand, when considering only climate change with the future scenarios, *J. valvatus*, *N. cyclamineus* and *T. capitellatus* were expected to contract their potential future habitat and *V. micrantha* to potentially expand its future range size (Alves et al., 2019). While our results contrast with those of Alves et al. (2019), results for the referred set of common species, this reflects probably the sources of data and methodological approach used to calibrate models and project potential changes in the future.

Climate and land use change have intricated effects on biodiversity, acting in synergic and antagonistic ways, depending on the species in question (Alves et al., 2019; García-Valdés et al., 2015). Climate change is likely to modify future range expansions of

species, but certain species characteristics (i.e. tolerance to drought, current distribution, and dispersal ability) can alter the effects of this potential change (García-Valdés et al., 2015). In 2015, García-Valdés et al. reported that it would take several centuries to observe the effects that climate change has on the distributional shifts of Spanish trees, anticipating the manifestation of the negative changes by the 2100's and not noticing any significant anthropogenic climate or land use changes at the study's temporal and geographical scales (García-Valdés et al., 2015). On the other hand, nowadays the effects of climate change are much more noticeable and of greater magnitude. As suggested by recent research, many European plants face potential extinction in the next decades, because of climate and land use changes, that alter plant diversity at local and regional scales (Boulangeat et al., 2014; Buse et al., 2015; García-Valdés et al., 2015; Moreira et al., 2023). Another recent study, that assessed the land use threats on global biodiversity of vascular plants for the year 2015, found that, by that same year, 11% of the vascular plant species were threatened with global extinction due to land use (Moreira et al., 2023), once more emphasizing the real and negative effects that environmental changes have on species distribution. Alves et al. (2019), while studying climate and land use changes on plants of conservation concern, found that for the land use scenarios considered, approximately 38% of their study species would contract their range, while 46% expanded and 16% remained stable.

Dou et al. (2023) while studying land use changes for Europe with the NFF scenarios, showed that independently of the NFF narrative considered, meeting sustainability targets will require European land systems to drastically change (Dou et al., 2023). The three perspectives showcase a similar direction of change, still 20% of Europe's land area will be altered based on the adopted scenario (Dou et al., 2023). Future projections of land systems for the Mediterranean region, indicate an intensification of croplands, that likely replace the traditional multi-functional agrosilvopastoral mosaics (Malek et al., 2018). For 2050, Dou et al. (2023) forecasts the expansion of natural grasslands and forests, and the intensification and diversification of productive areas (Dou et al., 2023). Moreira et al. (2023) found that the land systems cropland of minimal and high intensity contributes the most to the extinction threat of vascular plants due to land use. This reveals a need to reduce cropland impacts on plant biodiversity, i.e. by reducing the use of nutrient and pesticide or the implementation of agricultural diversification practices (crop diversification and organic amendment), which can be applied without compromising agricultural production, while promoting biodiversity (Moreira et al., 2023). To reduce biodiversity loss, some examples of measures that can be put into action to halt land use change are: restore abandoned croplands to native landscapes or reuse

them as pastures (to avoid the deforestation of new areas); land conversion; protection of the remaining wilderness areas; improvement of the management of existing protected areas; targeting demands and supply chains; dietary changes and deforestation; free trade accords (i.e. the proposal for a regulation on deforestation) (Moreira et al., 2023).

4.3. Implications for the conservation of SCCs

Assessing species range changes across IUCN categories

Overall, results showed that species that belong to the NT category have higher values of range change (will lose more area of distribution in the future) than either LC or VU. Interestingly, considering the most threatened categories, results showed that EN species showed slightly higher values for range change than VU species (i.e., EN is predicted to lose more area of distribution in the future than VU), while CR showed lower values than EN (CR is predicted to lose less area of distribution in the future than EN) (cf. Table 8). Regarding the percentage area occupied in the future by the species across IUCN categories (Table 9), we could expect the more threatened categories (CR, EN, and VU) to have lower values than the less threatened categories (NT and LC). In previous studies targeting SCCs, Alves et al., (2019) found that data deficient (DD) and endangered (EN) species were the most likely species, of the ones studied, to contract their ranges under the scenarios of climate and land use change considered. The same study also reported a trend for future range contraction across IUCN categories, except for CR species in a specific scenario of climate change (Alves et al., 2019). Navas et al. (2024), who studied populations of threatened plants, found that the species threat category was not relevant to identifying plant groups based on major patterns of land use (Navas et al., 2024). Overall, results obtained in this research are in line with previous research since no clear pattern was observed when assessing the level of threat of an IUCN category and the species range changes. The IUCN categorization of SCCs is mostly based on information about populations geographic range, size, or structure (IUCN, 2012), therefore, knowing more information about the species, such as habitat and environmental needs is fundamental to have more accurate current and future species distributions, that can better support conservation measures (Navas et al., 2024; Vaz et al., 2016). In addition, there is no sufficient data available to address the extinction risk of most plants, reflected as only 14% of the flowering plant species having their conservation status assessed by the IUCN Red List (Moreira et al., 2023). Maybe a revision or new parameters used for the IUCN classification of the species are needed, to better assess threatened species in the Anthropocene.

Assessing the impact of range changes in Natura 2000 network

For implementation of the Nature Futures Framework, targets were considered for PAs for each of the three scenarios: for NAC, the expansion of PAs focused on culturally valued agricultural landscapes; for NFN the PAs with terrestrial vertebrates are the priority of expansion; and, for NFS, the PAs to be expanded are areas that contribute to carbon accumulation (Dou et al., 2023).

The protected areas considered in this study (SAC's) represent about 13% of the Iberian Peninsula. Although there aren't baseline values for SCCs distributions within the considered protected areas, SCCs were predicted to decrease their potential suitable area within Natura 2000 SACs in the future, under the scenarios considered. Overall, our results showed small differences between the scenarios of change within the Natura 2000 Network SACs and followed the trends observed for the Iberian Peninsula (c.f. Table 8 and 10, section 3.3, and Tables ix: xi, section 6 – Appendix 4). The NFN scenario showed more positive values (less potential future habitat change), which could be the result of this scenario being more focused on Nature as a whole, leading to a more effective protection of the protected areas. Most species present range contraction since they are predicted to lose more grid units than they are predicted to gain, except for *J. valvatus* (for NAC and NFS scenarios), the only species predicted to only lose grid units and not gain grid units in the future within the Natura 2000 network (Table 10). Conversely, *G. nivallis* (NFN), *R. exaltatum* (NAC) and *X. vulgare* (NFN) were identified as species with range expansion, meaning that under the scenarios considered they may expand their habitat in the future.

Our results for *R. exaltatum*, showcase, for the NAC scenario, an increase of potential area of habitat within the Natura 2000 SACs. This agrees with Ribeiro et al. (2022) that states the same and found that while studying climate change with ecological niche models, in the future, most of the PAs specially designed to protect some important populations, would be in areas with high suitability for all species (Ribeiro et al., 2022). This supports the necessity of special PAs, the Plant Micro-reserves, to guarantee the preservation of these three species and found a model to evaluate the efficiency of a given PA in protecting any species, considering the climate change scenario (Ribeiro et al., 2022). In Spain, a study focused on land use and threatened plants, found that protected area systems have contributed to halt biodiversity losses due to urban sprawl, and establishing small-reserve systems has been particularly important to minimize the human impact on coastal areas (Navas et al., 2024).

4.4. Limitations and future perspectives

Despite our results, there are still some limitations identified during our study, and thus room for improvement.

The defined area for this study, the Iberian Peninsula, may constitute a limitation. Despite the collected data on species occurrences being restricted to the continental area of the Iberian Peninsula, some of the targeted species have occurrences outside of this geographic area (i.e., *A. baetica* - north Africa and France; *J. valvatus* - north Africa; and *M. segetalis* - Canary Islands). Therefore, the resulting models may not be able to capture all the potential suitable habitat for such species. This can lead to biased projections, by altering the response curves on extreme environmental conditions since the models fail to gather all species suitable habitat (Barbet-Massin et al., 2012; Reino et al., 2018). Nonetheless, the occurrences outside of the Iberian Peninsula, namely north Africa, and southwestern France, were assumed to be within the same environmental (climatic and land use) conditions as the ones occurring in the study area.

Regarding the targeted species, and considering they are species of conservation concern, collecting and harmonizing species occurrences was challenging. Data available for some of the targeted SCCs was limited, in number and at the spatial/temporal scale. Regarding the temporal scale, the newer occurrences date to 2018, in agreement with the timeline of the current conditions used for the environmental variables. So, a future study would benefit of including more study species and using other modelling approaches, such as those allowing to model species with narrower distributions (i.e., see Lomba et al. (2010)). This study focused on SCCs, which are particularly difficult to model, since they fit the characteristics of the paradox of rare species. Because of this, the predictions of species distributions can be biased to areas where the species are more probable of existing since they are rarely successfully observed by sampling systems (Jeliazkov et al., 2022). Besides that, this study targeted species that are protected, so we considered the IUCN categories each species represents, and used this classification to assess changes within those same categories. Since we have a low number of species, the IUCN categories may not be sufficiently well represented, especially the Endangered and Critically Endangered classes, which only have one representative species each.

Other possible caveats relate with the identification of the species and positional errors i.e., lack of one or both spatial coordinates, coordinates set as zero, switched coordinates, or duplicated records. These records would have been used, as long as

they fall inside the study area, leading to biased niche estimates (Sillero et al., 2021). To prevent these types of mistakes, we removed occurrences without coordinates, occurrence points were checked by plotting and visually inspecting species records on a map, and since we used the EEA 10km x 10km grid, the duplicated records were removed.

For the modelling of the species current distributions, we used climatic, land systems and topographic variables, but for the prediction of the future ranges we only considered the Nature Futures Framework and respective scenarios of land systems for 2050. These scenarios already incorporate climate predictions so it would be redundant to use climate change scenarios, and potentially result in double counting of the climate contribution on the species future distribution. Other limitations of the NFF scenarios relates include: the need for a wider range of observation data of drivers to forecast responses under different policy interventions, so high-resolution remote-sensing and other observational evidence could contribute to increasing the predictive power of the changes in biodiversity (Kim et al., 2023); the scenarios may not be able to fully encapsulate all worldviews, so the current models may not yet be well adapted to different perspectives (IPBES, 2022a); not all sustainability targets can be completely met by the scenarios, or how the land systems will respond to certain targets (e.g., how land systems will react to the per-unit nitrogen reduction target) (Dou et al., 2023). Nonetheless, the NFF and its integration with the study of land systems and land use changes are a novel approach, particularly for the study of SCCs distribution under scenarios of change, to improve and support the implementation of tailored conservation actions.

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6. Supplementary Material

Appendix 1 – Selection of variables

In this section we present the correlation values for the three types of variables considered for this thesis: climatic (Table i), topographic (Table ii) and land systems (Table iii).

The nineteen climatic variables considered are: bio1 - mean annual air temperature; bio2 - mean diurnal air temperature range; bio3 - isothermality, bio4 - temperature seasonality; bio5 - mean daily maximum air temperature of the warmest month; bio6 - mean daily minimum air temperature of the coldest month; bio7 - annual range of air temperature; bio8 - mean daily mean air temperatures of the wettest quarter; bio9 - mean daily mean air temperatures of the driest quarter; bio10 - mean daily mean air temperatures of the warmest quarter; bio11 - mean daily mean air temperatures of the coldest quarter; bio12 - annual precipitation amount; bio13 - precipitation amount of the wettest month; bio14 - precipitation amount of the driest month; bio15 - precipitation seasonality; bio16 - mean monthly precipitation amount of the wettest quarter; bio17 - mean monthly precipitation amount of the driest quarter; bio18 - mean monthly precipitation amount of the warmest quarter; bio19 - mean monthly precipitation amount of the coldest quarter.

The four topographic variables considered are: DEM (Digital Elevation Model), Hillshade, TRI (Terrain Ruggedness Index) and Slope.

The twenty one land systems variables considered are: LU11 - water body; LU12 – wetland; LU21 - low-intensity settlement; LU22 - medium intensity settlement; LU23 - high intensity settlement; LU31 - extensive perm-crops; LU32 - intensive perm-crops; LU41 - low-intensity forest; LU42 - medium-intensity forest; LU43 - high-intensity forest; LU51 low-intensity grassland; LU52 - medium-intensity grassland; LU53 - high-intensity grassland; LU61 - low-intensity cropland; LU62 - medium-intensity cropland; LU63 - high-intensity cropland; LU71 - forest/shrubs and

cropland mosaics; LU72 - forest/shrubs and grassland mosaics; LU74 - forest/shrubs and bare mosaics; LU75 - forest/shrubs and mixed agriculture mosaics; LU80 – shrub; LU90 - bare and rocks; LU731 - low-intensity agricultural mosaics; LU732 - medium-intensity agricultural mosaics; LU733 - high-intensity agricultural mosaics.

For each value, a colour is assigned to it based on the correlation between the variables – green (-0,49 to 0 and 0 to 0,49), yellow (-0,65 to -0,50 and 0,50 to 0,65) and red (-1 to -0,66 and 0,66 to 1).

Table i- Correlation values for the twenty climatic variables.

	bio1	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19
bio1	1	-0,09	-0,22	0,02	0,74	0,85	0,02	0,59	0,72	0,89	0,92	-0,32	-0,13	-0,65	0,64	-0,13	-0,63	-0,61	-0,09
bio2	-0,09	1	0,48	0,81	0,55	-0,56	0,92	-0,31	0,17	0,28	-0,41	-0,44	-0,48	-0,26	-0,07	-0,47	-0,30	-0,31	-0,36
bio3	-0,22	0,48	1	-0,07	-0,07	-0,26	0,14	-0,39	-0,07	-0,23	-0,19	0,20	0,18	0,09	0,09	0,19	0,05	-0,01	0,29
bio4	0,02	0,81	-0,07	1	0,67	-0,49	0,97	-0,06	0,22	0,48	-0,37	-0,61	-0,66	-0,27	-0,22	-0,66	-0,29	-0,26	-0,62
bio5	0,74	0,55	-0,07	0,67	1	0,28	0,68	0,30	0,70	0,95	0,42	-0,62	-0,52	-0,70	0,39	-0,51	-0,70	-0,68	-0,43
bio6	0,85	-0,56	-0,26	-0,49	0,28	1	-0,51	0,57	0,51	0,52	0,98	0,03	0,21	-0,40	0,61	0,20	-0,36	-0,37	0,20
bio7	0,02	0,92	0,14	0,97	0,68	-0,51	1	-0,16	0,24	0,45	-0,37	-0,58	-0,62	-0,32	-0,12	-0,61	-0,35	-0,33	-0,54
bio8	0,59	-0,31	-0,39	-0,06	0,30	0,57	-0,16	1	0,12	0,49	0,58	-0,41	-0,30	-0,24	0,05	-0,33	-0,19	-0,11	-0,44
bio9	0,72	0,17	-0,07	0,22	0,70	0,51	0,24	0,12	1	0,74	0,58	-0,28	-0,16	-0,63	0,52	-0,15	-0,62	-0,69	-0,03
bio10	0,89	0,28	-0,23	0,48	0,95	0,52	0,45	0,49	0,74	1	0,64	-0,56	-0,42	-0,70	0,47	-0,42	-0,69	-0,66	-0,37
bio11	0,92	-0,41	-0,19	-0,37	0,42	0,98	-0,37	0,58	0,58	0,64	1	-0,06	0,13	-0,50	0,67	0,13	-0,47	-0,46	0,15
bio12	-0,32	-0,44	0,20	-0,61	-0,62	0,03	-0,58	-0,41	-0,28	-0,56	-0,06	1	0,96	0,60	0,04	0,96	0,62	0,56	0,92
bio13	-0,13	-0,48	0,18	-0,66	-0,52	0,21	-0,62	-0,30	-0,16	-0,42	0,13	0,96	1	0,39	0,29	1,00	0,41	0,37	0,97
bio14	-0,65	-0,26	0,09	-0,27	-0,70	-0,40	-0,32	-0,24	-0,63	-0,70	-0,50	0,60	0,39	1	-0,68	0,38	0,99	0,97	0,28

bio15	0,64	-0,07	0,09	-0,22	0,39	0,61	-0,12	0,05	0,52	0,47	0,67	0,04	0,29	-0,68	1	0,30	-0,68	-0,67	0,38
bio16	-0,13	-0,47	0,19	-0,66	-0,51	0,20	-0,61	-0,33	-0,15	-0,42	0,13	0,96	1,00	0,38	0,30	1	0,40	0,35	0,97
bio17	-0,63	-0,30	0,05	-0,29	-0,70	-0,36	-0,35	-0,19	-0,62	-0,69	-0,47	0,62	0,41	0,99	-0,68	0,40	1	0,97	0,28
bio18	-0,61	-0,31	-0,01	-0,26	-0,68	-0,37	-0,33	-0,11	-0,69	-0,66	-0,46	0,56	0,37	0,97	-0,67	0,35	0,97	1	0,22
bio19	-0,09	-0,36	0,29	-0,62	-0,43	0,20	-0,54	-0,44	-0,03	-0,37	0,15	0,92	0,97	0,28	0,38	0,97	0,28	0,22	1

Table ii - Correlation values for the four topographic variables.

	DEM	Hillshade	TRI	Slope
DEM	1	-0,30	0,47	0,47
Hillshade	-0,30	1	-0,58	-0,57
TRI	0,47	-0,58	1	1,00
Slope	0,47	-0,57	1,00	1

Table iii - Correlation values for the twenty-six land systems variables.

	LU11	LU12	LU21	LU22	LU23	LU31	LU32	LU41	LU42	LU43	LU51	LU52	LU53	LU61	LU62	LU63	LU71	LU72	LU74	LU75	LU80	LU90	LU731	LU732	LU733
LU11	1	0,22	-0,04	-0,03	-0,01	0,01	-0,04	-0,03	-0,03	-0,02	0,03	-0,01	-0,01	-0,04	-0,04	-0,01	-0,08	-0,03	0,04	0,04	-0,03	0,01	-0,03	0,00	0,00
LU12	0,22	1	0,01	0,09	0,08	-0,02	-0,03	-0,13	-0,05	-0,01	-0,05	0,00	0,02	-0,03	0,01	0,05	-0,09	-0,08	0,01	-0,03	-0,09	0,01	-0,04	0,02	0,00
LU21	-0,04	0,01	1	0,02	-0,05	0,09	0,01	-0,19	-0,04	0,09	-0,08	-0,01	0,02	0,03	0,04	0,03	0,02	-0,10	-0,04	-0,08	-0,08	0,00	0,00	0,02	0,01
LU22	-0,03	0,09	0,02	1	0,46	0,04	-0,02	-0,19	-0,09	0,02	-0,07	-0,02	0,01	-0,04	-0,07	-0,01	-0,12	-0,13	-0,03	-0,09	-0,12	-0,02	-0,06	-0,03	-0,01
LU23	-0,01	0,08	-0,05	0,46	1	-0,01	-0,03	-0,14	-0,08	-0,03	-0,06	-0,02	0,00	-0,05	-0,06	-0,01	-0,12	-0,09	-0,03	-0,06	-0,10	-0,01	-0,06	-0,03	-0,01
LU31	0,01	-0,02	0,09	0,04	-0,01	1	0,03	-0,15	-0,13	-0,07	-0,09	-0,04	-0,03	-0,04	-0,12	-0,05	-0,13	-0,15	-0,04	-0,02	-0,08	-0,03	-0,09	-0,06	-0,02
LU32	-0,04	-0,03	0,01	-0,02	-0,03	0,03	1	-0,17	-0,17	-0,11	-0,08	-0,04	-0,02	0,05	-0,06	-0,05	-0,17	-0,15	-0,05	-0,08	-0,16	-0,04	-0,04	-0,05	-0,01
LU41	-0,03	-0,13	-0,19	-0,19	-0,14	-0,15	-0,17	1	-0,11	-0,23	0,01	0,02	-0,02	-0,19	-0,29	-0,08	-0,15	0,20	0,03	0,08	0,00	-0,01	-0,11	-0,04	-0,03

LU42	-0,03	-0,05	-0,04	-0,09	-0,08	-0,13	-0,17	-0,11	1	0,13	-0,06	-0,05	0,00	-0,13	-0,20	-0,04	0,07	0,09	0,02	0,00	0,05	-0,04	-0,12	-0,01	0,00
LU43	-0,02	-0,01	0,09	0,02	-0,03	-0,07	-0,11	-0,23	0,13	1	-0,11	-0,05	0,00	-0,04	-0,16	-0,04	0,13	-0,12	0,03	-0,07	0,04	0,01	-0,11	0,02	0,01
LU51	0,03	-0,05	-0,08	-0,07	-0,06	-0,09	-0,08	0,01	-0,06	-0,11	1	0,04	-0,03	-0,08	-0,13	-0,05	-0,18	0,41	0,04	0,08	-0,02	0,10	0,32	-0,02	-0,02
LU52	-0,01	0,00	-0,01	-0,02	-0,02	-0,04	-0,04	0,02	-0,05	-0,05	0,04	1	0,05	-0,04	-0,07	-0,02	-0,10	0,25	-0,01	0,07	-0,05	-0,01	0,07	0,26	0,02
LU53	-0,01	0,02	0,02	0,01	0,00	-0,03	-0,02	-0,02	0,00	0,00	-0,03	0,05	1	-0,01	-0,04	-0,01	-0,04	0,13	0,02	-0,01	-0,02	0,00	-0,03	0,10	0,44
LU61	-0,04	-0,03	0,03	-0,04	-0,05	-0,04	0,05	-0,19	-0,13	-0,04	-0,08	-0,04	-0,01	1	-0,15	-0,06	0,17	-0,16	-0,06	-0,01	-0,13	-0,04	0,18	0,06	0,03
LU62	-0,04	0,01	0,04	-0,07	-0,06	-0,12	-0,06	-0,29	-0,20	-0,16	-0,13	-0,07	-0,04	-0,15	1	0,00	0,07	-0,25	-0,09	-0,06	-0,26	-0,05	0,07	-0,03	-0,02
LU63	-0,01	0,05	0,03	-0,01	-0,01	-0,05	-0,05	-0,08	-0,04	-0,04	-0,05	-0,02	-0,01	-0,06	0,00	1	0,04	-0,07	-0,03	-0,04	-0,08	-0,02	0,02	0,02	0,00
LU71	-0,08	-0,09	0,02	-0,12	-0,12	-0,13	-0,17	-0,15	0,07	0,13	-0,18	-0,10	-0,04	0,17	0,07	0,04	1	-0,21	-0,08	-0,09	0,02	-0,07	0,03	0,04	0,00
LU72	-0,03	-0,08	-0,10	-0,13	-0,09	-0,15	-0,15	0,20	0,09	-0,12	0,41	0,25	0,13	-0,16	-0,25	-0,07	-0,21	1	0,05	0,01	0,15	0,03	0,07	0,05	0,03
LU74	0,04	0,01	-0,04	-0,03	-0,03	-0,04	-0,05	0,03	0,02	0,03	0,04	-0,01	0,02	-0,06	-0,09	-0,03	-0,08	0,05	1	-0,05	0,11	0,37	-0,06	-0,02	0,00
LU75	0,04	-0,03	-0,08	-0,09	-0,06	-0,02	-0,08	0,08	0,00	-0,07	0,08	0,07	-0,01	-0,01	-0,06	-0,04	-0,09	0,01	-0,05	1	-0,10	-0,03	0,00	0,02	-0,01
LU80	-0,03	-0,09	-0,08	-0,12	-0,10	-0,08	-0,16	0,00	0,05	0,04	-0,02	-0,05	-0,02	-0,13	-0,26	-0,08	0,02	0,15	0,11	-0,10	1	0,01	-0,12	-0,06	-0,03
LU90	0,01	0,01	0,00	-0,02	-0,01	-0,03	-0,04	-0,01	-0,04	0,01	0,10	-0,01	0,00	-0,04	-0,05	-0,02	-0,07	0,03	0,37	-0,03	0,01	1	-0,04	-0,02	0,00
LU731	-0,03	-0,04	0,00	-0,06	-0,06	-0,09	-0,04	-0,11	-0,12	-0,11	0,32	0,07	-0,03	0,18	0,07	0,02	0,03	0,07	-0,06	0,00	-0,12	-0,04	1	-0,01	-0,02
LU732	0,00	0,02	0,02	-0,03	-0,03	-0,06	-0,05	-0,04	-0,01	0,02	-0,02	0,26	0,10	0,06	-0,03	0,02	0,04	0,05	-0,02	0,02	-0,06	-0,02	-0,01	1	0,24
LU733	0,00	0,00	0,01	-0,01	-0,01	-0,02	-0,01	-0,03	0,00	0,01	-0,02	0,02	0,44	0,03	-0,02	0,00	0,00	0,03	0,00	-0,01	-0,03	0,00	-0,02	0,24	1

Appendix 2 – Methods

In this section we present the Number of Pseudoabsences and Occurrences and the Area occupied by the gathered occurrences of the study species -Table iv.

Table iv - Number of Pseudoabsences and Occurrences (in grid units) used for the modelling of the species, as well as the area occupied by the species Occurrences (in km²).

Species	Number of Pseudoabsences (grid units)	Number of Occurrences (grid units)	Area of Occurrences (km ²)
ATRBAE	171	57	5700001741,00
DORPEN	2541	847	82497241294,11
EUPNEV	525	175	17600005383,79
GALNIV	279	93	8571786110,43
JUNVAL	213	71	6122847857,00
MELSEG	201	67	5292130366,53
NARCYC	423	141	13460039065,38
RHAEXA	114	38	3800001160,68
THYCAP	186	62	5016349276,58
VERMIC	429	143	14067436871,92
VIOCAZ	111	37	3700001129,91
XIPVUL	849	283	26845988432,65

Appendix 3 – Models

In this section we present validation (Table v) and calibration (Table vi) scores for each of the eleven algorithms used in the modelling process (ANN, CTA, FDA, GAM, GBM, GLM, MARS, MAXNET, RF, SRE, XGBOOST), for each of the twelve study species. The evaluation was made by AUC (Area Under the Curve) and TSS (True Skill Statistics).

We also present the Evaluation values of the models for the twelve targeted species, measured by AUC (Area Under the Curve), with values for cutoff, sensitivity, and specificity – Table vii.

On Table viii, we present the values of the potential suitable habitat (current conditions), in the Iberian Peninsula, for each of the twelve targeted. These values are expressed as number of grid cells and km².

Table v - Validation Scores evaluated by AUC and TSS. Mean values for each of the eleven algorithms used, by the twelve targeted species.

		ATRBAE		DORPEN		EUPNEV		GALNIV		JUNVAL	
algorithm	metric eval	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
ANN	ROC	0,781	0,087	0,625	0,072	0,751	0,079	0,874	0,086	0,803	0,098
ANN	TSS	0,569	0,163	0,198	0,112	0,430	0,128	0,606	0,159	0,560	0,179
CTA	AUC	0,892	0,045	0,644	0,023	0,794	0,040	0,842	0,051	0,879	0,060
CTA	TSS	0,752	0,073	0,256	0,040	0,560	0,081	0,653	0,091	0,741	0,102
FDA	AUC	0,926	0,015	0,677	0,021	0,860	0,034	0,911	0,033	0,942	0,035
FDA	TSS	0,732	0,041	0,271	0,042	0,586	0,074	0,660	0,094	0,736	0,110
GAM	AUC	0,994	0,012	0,681	0,022	0,855	0,035	0,861	0,057	0,899	0,063
GAM	TSS	0,973	0,050	0,270	0,040	0,588	0,068	0,583	0,114	0,705	0,133
GBM	AUC	0,988	0,006	0,710	0,021	0,878	0,030	0,932	0,025	0,958	0,031
GBM	TSS	0,918	0,029	0,302	0,043	0,601	0,074	0,685	0,088	0,775	0,108
GLM	AUC	0,928	0,015	0,657	0,021	0,871	0,031	0,885	0,040	0,944	0,033
GLM	TSS	0,772	0,043	0,248	0,042	0,601	0,071	0,628	0,098	0,776	0,100
MARS	AUC	0,945	0,015	0,676	0,022	0,863	0,032	0,901	0,039	0,939	0,038
MARS	TSS	0,795	0,039	0,271	0,043	0,587	0,070	0,655	0,100	0,757	0,106
MAXNET	AUC	0,932	0,014	0,686	0,022	0,874	0,031	0,896	0,035	0,961	0,026
MAXNET	TSS	0,768	0,037	0,286	0,042	0,616	0,068	0,628	0,100	0,780	0,098
RF	AUC	0,999	0,001	0,706	0,018	0,873	0,032	0,934	0,026	0,961	0,027
RF	TSS	0,988	0,009	0,230	0,038	0,557	0,092	0,660	0,097	0,760	0,118
SRE	AUC	0,726	0,023	0,556	0,017	0,758	0,037	0,714	0,058	0,847	0,061
SRE	TSS	0,453	0,047	0,112	0,033	0,516	0,073	0,428	0,117	0,694	0,123
XGBOOST	AUC	1,000	0,000	0,684	0,021	0,857	0,033	0,927	0,027	0,950	0,033
XGBOOST	TSS	1,000	0,000	0,187	0,036	0,506	0,090	0,645	0,094	0,745	0,116
		MELSEG		NARCYC		RHAEXA		THYCAP		VERMIC	
algorithm	metric eval	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
ANN	AUC	0,726	0,126	0,947	0,026	0,751	0,087	0,797	0,205	0,826	0,037
ANN	TSS	0,377	0,210	0,872	0,052	0,451	0,164	0,574	0,406	0,615	0,071
CTA	AUC	0,803	0,067	0,954	0,019	0,736	0,090	0,913	0,046	0,835	0,037
CTA	TSS	0,568	0,118	0,895	0,044	0,440	0,164	0,812	0,091	0,661	0,067

FDA	AUC	0,870	0,048	0,981	0,011	0,854	0,071	0,969	0,030	0,881	0,033
FDA	TSS	0,608	0,107	0,900	0,046	0,561	0,162	0,817	0,093	0,672	0,071
GAM	AUC	0,824	0,069	0,964	0,036	0,708	0,095	0,913	0,052	0,884	0,031
GAM	TSS	0,541	0,147	0,866	0,080	0,388	0,189	0,774	0,120	0,634	0,077
GBM	AUC	0,881	0,044	0,984	0,010	0,866	0,069	0,976	0,024	0,903	0,028
GBM	TSS	0,555	0,142	0,894	0,052	0,575	0,179	0,838	0,091	0,685	0,074
GLM	AUC	0,841	0,054	0,983	0,011	0,821	0,081	0,966	0,023	0,893	0,028
GLM	TSS	0,617	0,116	0,909	0,045	0,524	0,159	0,838	0,098	0,656	0,063
MARS	AUC	0,874	0,054	0,982	0,011	0,848	0,077	0,971	0,027	0,896	0,032
MARS	TSS	0,626	0,113	0,912	0,040	0,544	0,165	0,841	0,087	0,664	0,072
MAXNET	AUC	0,875	0,044	0,984	0,010	0,865	0,073	0,975	0,019	0,908	0,024
MAXNET	TSS	0,614	0,103	0,923	0,037	0,568	0,157	0,828	0,094	0,681	0,065
RF	AUC	0,874	0,047	0,983	0,010	0,864	0,077	0,978	0,020	0,902	0,029
RF	TSS	0,495	0,133	0,862	0,067	0,563	0,179	0,805	0,112	0,606	0,092
SRE	AUC	0,699	0,060	0,863	0,047	0,718	0,084	0,841	0,073	0,786	0,047
SRE	TSS	0,398	0,120	0,727	0,095	0,435	0,169	0,683	0,146	0,571	0,094
XGBOOST	AUC	0,872	0,045	0,978	0,014	0,842	0,084	0,968	0,025	0,886	0,029
XGBOOST	TSS	0,490	0,136	0,862	0,058	0,508	0,197	0,806	0,107	0,545	0,084

		VIOCAZ		XIPVUL	
algorithm	metric eval	mean	sd	mean	sd
ANN	AUC	0,813	0,120	0,636	0,085
ANN	TSS	0,602	0,215	0,231	0,133
CTA	AUC	0,850	0,084	0,717	0,045
CTA	TSS	0,682	0,160	0,352	0,078
FDA	AUC	0,912	0,069	0,739	0,037
FDA	TSS	0,668	0,168	0,344	0,071
GAM	AUC	0,815	0,087	0,737	0,039
GAM	TSS	0,604	0,172	0,352	0,069
GBM	AUC	0,911	0,075	0,769	0,035
GBM	TSS	0,722	0,157	0,385	0,068
GLM	AUC	0,894	0,084	0,750	0,035
GLM	TSS	0,694	0,165	0,376	0,066
MARS	AUC	0,891	0,089	0,739	0,036
MARS	TSS	0,638	0,177	0,330	0,069
MAXNET	AUC	0,914	0,076	0,756	0,035
MAXNET	TSS	0,712	0,165	0,365	0,075
RF	AUC	0,895	0,085	0,761	0,033
RF	TSS	0,722	0,156	0,338	0,067
SRE	AUC	0,780	0,084	0,639	0,032
SRE	TSS	0,561	0,168	0,278	0,064
XGBOOST	AUC	0,899	0,080	0,739	0,032
XGBOOST	TSS	0,656	0,165	0,279	0,065

Table vi - Calibration Scores evaluated by AUC and TSS. Mean values for each of the eleven algorithms used, by the twelve targeted species.

		ATRBAE		DORPEN		EUPNEV		GALNIV		JUNVAL	
algorithm	metric eval	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
ANN	AUC	0,720	0,110	0,661	0,085	0,777	0,070	0,921	0,092	0,839	0,096
ANN	TSS	0,403	0,203	0,257	0,132	0,523	0,114	0,789	0,182	0,674	0,170
CTA	AUC	0,801	0,065	0,716	0,040	0,860	0,031	0,929	0,041	0,935	0,025

CTA	TSS	0,557	0,129	0,383	0,064	0,688	0,049	0,820	0,066	0,851	0,039
FDA	AUC	0,875	0,048	0,697	0,006	0,882	0,011	0,941	0,013	0,964	0,008
FDA	TSS	0,584	0,125	0,313	0,014	0,652	0,029	0,767	0,032	0,822	0,027
GAM	AUC	0,768	0,086	0,714	0,005	0,909	0,010	0,975	0,012	0,988	0,009
GAM	TSS	0,483	0,149	0,331	0,010	0,712	0,023	0,895	0,044	0,941	0,044
GBM	AUC	0,894	0,042	0,790	0,003	0,956	0,007	0,990	0,003	0,995	0,001
GBM	TSS	0,582	0,117	0,435	0,009	0,792	0,020	0,933	0,015	0,946	0,013
GLM	AUC	0,883	0,050	0,668	0,007	0,884	0,012	0,911	0,015	0,966	0,009
GLM	TSS	0,623	0,134	0,273	0,012	0,657	0,028	0,708	0,034	0,866	0,032
MARS	AUC	0,872	0,049	0,703	0,006	0,893	0,011	0,948	0,012	0,972	0,009
MARS	TSS	0,592	0,119	0,322	0,013	0,673	0,027	0,801	0,033	0,865	0,034
MAXNET	AUC	0,885	0,051	0,709	0,006	0,900	0,010	0,923	0,012	0,975	0,006
MAXNET	TSS	0,623	0,121	0,331	0,011	0,693	0,022	0,732	0,035	0,860	0,027
RF	AUC	0,883	0,049	1,000	0,000	0,999	0,001	0,999	0,001	0,999	0,000
RF	TSS	0,517	0,131	0,993	0,002	0,981	0,007	0,988	0,006	0,986	0,006
SRE	AUC	0,723	0,087	0,560	0,007	0,767	0,015	0,753	0,018	0,863	0,009
SRE	TSS	0,445	0,173	0,121	0,014	0,534	0,031	0,505	0,037	0,726	0,019
XGBOOST	AUC	0,851	0,058	1,000	0,000	1,000	0,000	1,000	0,000	1,000	0,000
XGBOOST	TSS	0,473	0,151	0,991	0,003	1,000	0,000	1,000	0,000	1,000	0,000

		MELSEG		NARCYC		RHAEXA		THYCAP		VERMIC	
algorithm	metric eval	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
ANN	AUC	0,830	0,108	0,956	0,020	0,804	0,046	0,822	0,221	0,846	0,023
ANN	TSS	0,611	0,197	0,908	0,038	0,593	0,096	0,641	0,439	0,671	0,034
CTA	AUC	0,882	0,044	0,972	0,009	0,883	0,054	0,963	0,027	0,866	0,033
CTA	TSS	0,726	0,067	0,939	0,015	0,719	0,083	0,911	0,044	0,721	0,053
FDA	AUC	0,902	0,017	0,986	0,003	0,917	0,023	0,983	0,006	0,911	0,010
FDA	TSS	0,705	0,034	0,925	0,013	0,739	0,055	0,891	0,023	0,722	0,023
GAM	AUC	0,943	0,023	0,995	0,004	1,000	0,000	0,999	0,003	0,934	0,012
GAM	TSS	0,827	0,060	0,973	0,017	1,000	0,000	0,992	0,017	0,776	0,033
GBM	AUC	0,985	0,005	0,998	0,001	0,991	0,005	0,998	0,001	0,973	0,004
GBM	TSS	0,893	0,024	0,969	0,006	0,933	0,028	0,976	0,011	0,853	0,017
GLM	AUC	0,879	0,017	0,987	0,004	0,878	0,031	0,986	0,008	0,907	0,010
GLM	TSS	0,696	0,040	0,942	0,012	0,671	0,073	0,930	0,027	0,713	0,023
MARS	AUC	0,907	0,029	0,989	0,004	0,946	0,021	0,989	0,007	0,920	0,010
MARS	TSS	0,730	0,054	0,951	0,010	0,798	0,060	0,937	0,024	0,733	0,021
MAXNET	AUC	0,909	0,015	0,989	0,003	0,933	0,014	0,988	0,005	0,934	0,007
MAXNET	TSS	0,722	0,037	0,942	0,008	0,750	0,039	0,906	0,024	0,746	0,022
RF	AUC	0,999	0,001	1,000	0,000	0,999	0,001	1,000	0,000	1,000	0,000
RF	TSS	0,984	0,009	0,991	0,005	0,987	0,011	0,993	0,006	0,982	0,007
SRE	AUC	0,710	0,030	0,884	0,005	0,784	0,036	0,849	0,013	0,800	0,011
SRE	TSS	0,419	0,061	0,768	0,011	0,567	0,071	0,698	0,025	0,600	0,022
XGBOOST	AUC	1,000	0,000	1,000	0,000	1,000	0,000	1,000	0,000	1,000	0,000
XGBOOST	TSS	1,000	0,000	1,000	0,000	1,000	0,000	1,000	0,000	1,000	0,000

algorithm	metric eval	VIOCAZ		XIPVUL	
		mean	sd	mean	sd
ANN	AUC	0,902	0,075	0,666	0,101
ANN	TSS	0,796	0,137	0,313	0,157
CTA	AUC	0,912	0,028	0,807	0,041
CTA	TSS	0,804	0,050	0,533	0,074
FDA	AUC	0,970	0,012	0,769	0,011
FDA	TSS	0,849	0,040	0,416	0,023
GAM	AUC	1,000	0,000	0,798	0,012
GAM	TSS	1,000	0,000	0,463	0,025
GBM	AUC	0,996	0,002	0,884	0,009
GBM	TSS	0,961	0,017	0,625	0,020
GLM	AUC	0,965	0,015	0,768	0,011
GLM	TSS	0,842	0,050	0,423	0,020
MARS	AUC	0,983	0,010	0,781	0,011
MARS	TSS	0,903	0,048	0,429	0,023
MAXNET	AUC	0,976	0,008	0,794	0,011
MAXNET	TSS	0,857	0,030	0,453	0,023
RF	AUC	0,999	0,001	1,000	0,000
RF	TSS	0,986	0,010	0,988	0,004
SRE	AUC	0,858	0,021	0,644	0,011
SRE	TSS	0,715	0,041	0,288	0,022
XGBOOST	AUC	1,000	0,000	1,000	0,000
XGBOOST	TSS	1,000	0,000	1,000	0,000

Table vii - Evaluation of the models for the twelve targeted species, measured by AUC (Area Under the Curve), with respective values of cutoff (the associated cut-off used to transform the continuous values into binary), sensitivity (the sensibility obtained on fitted values with the threshold), and specificity (the specificity obtained on fitted values with the threshold).

	AUC	Cutoff	Sensitivity	Specificity
ATRBAE	0,96	548,50	92,98	89,97
DORPEN	0,93	471,50	85,71	82,35
EUPNEV	0,93	435,50	94,89	78,94
GALNIV	0,97	431,50	98,93	86,65
JUNVAL	0,98	360,50	100,00	89,77
MELSEG	0,94	444,50	98,51	79,44
NARCYC	0,99	457,00	100,00	95,10
RHAEXA	0,97	513,50	92,11	90,33
THYCAP	0,99	423,50	100,00	94,18
VERMIC	0,95	412,00	95,04	81,82
VIOCAZ	0,99	363,50	100,00	91,32
XIPVUL	0,89	451,50	89,40	74,36

Table viii - Overview of the potential suitable habitat (current conditions) for each of the twelve targeted Species of Conservation Concern. These values are expressed as number of grid cells occupied in the Iberian Peninsula and km².

Species	Area of potential suitable habitat (number of grid cells)	Area of potential suitable habitat (km ²)
ATRBAE	687	68031,43
DORPEN	1649	162296,69
EUPNEV	1414	140586,88
GALNIV	859	82001,91
JUNVAL	742	68324,25
MELSEG	1288	116413,92
NARCYC	424	37305,84
RHAEXA	693	69049,11
THYCAP	417	38243,61
VERMIC	1267	119728,35
VIOCAZ	680	66536,73
XIPVUL	1779	169005,20

Appendix 4 – Results

Here, in Figures i to xii, we present the location of the potential suitable habitat area for the twelve study species, modelled for the current conditions.

In the tables ix, x and xi, we present the predicted future suitable area occupied by our twelve study species, separated by each of the NFF scenarios - NAC, NFN and NFS, respectively. These results are represented, in grid units, as: Loss (number of grid units predicted to be lost), Stable 0 (number of grid units predicted to remain unoccupied), Stable 1 (number of grid units predicted to remain occupied by the species), Gain (number of grid units predicted to be gained), Percentage of Loss (in percentage), Percentage of Gain (in percentage), Species Range Change (Percentage of Gain minus Percentage of Loss, in percentage), Current Range Size (number of grid units predicted to be occupied in the current conditions) and Future Range Size (number of grid units predicted to be occupied in the future conditions). The mean value, of all twelve species, for each parameter was also calculated.

In the figures xii, xiv and xv, it's represented the percentage of Species Range Change (comparison between the modelled species range for the future and current conditions) for each of the twelve study species, separated by NFF scenario.

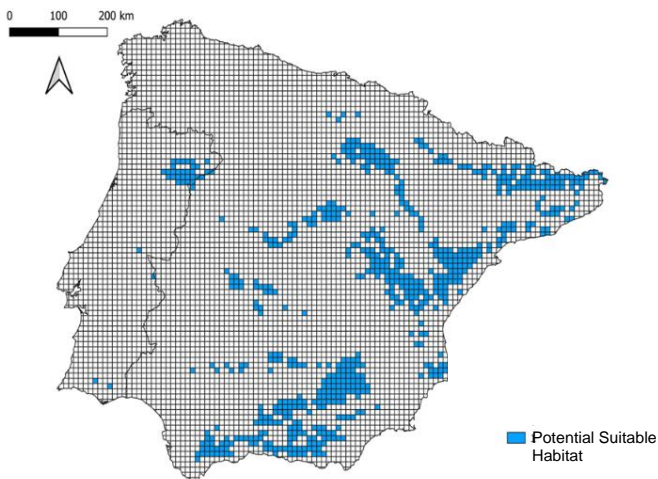


Figure i – Representation and Location of the Potential Suitable Habitat for *Atropa baetica*, for the current conditions.

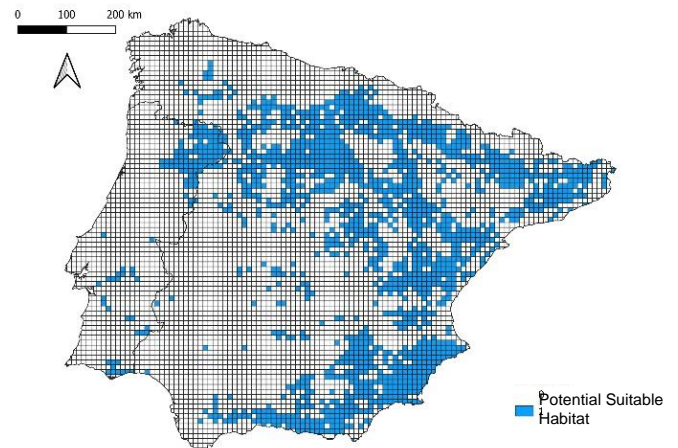


Figure ii - Representation and Location of the Potential Suitable Habitat for *Dorycnium pentaphyllum*, for the current conditions.

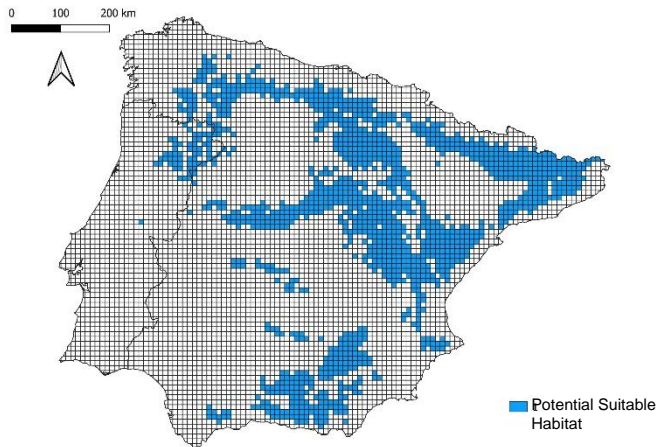


Figure iv - Representation and Location of the Potential Suitable Habitat for *Euphorbia nevadensis*, for the current conditions.

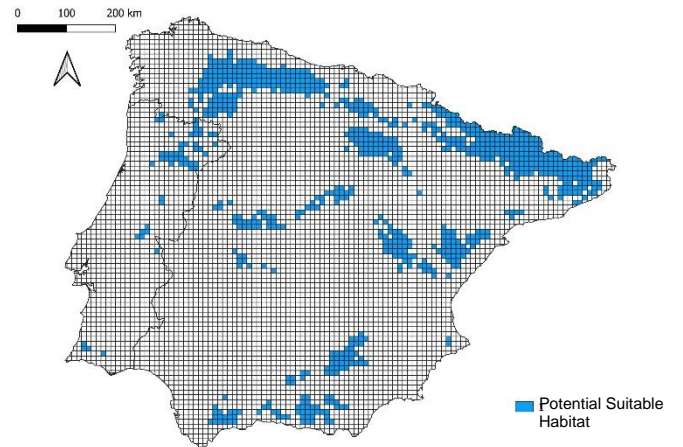


Figure iii - Representation and Location of the Potential Suitable Habitat for *Galanthus nivallis*, for the current conditions.

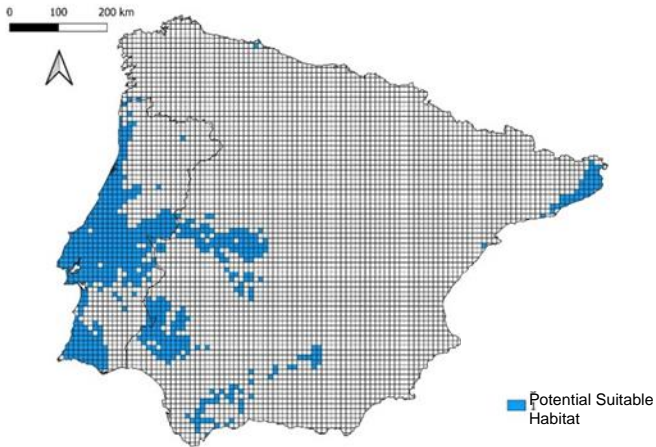


Figure vi - Representation and Location of the Potential Suitable Habitat for *Juncus valvatus*, for the current conditions.

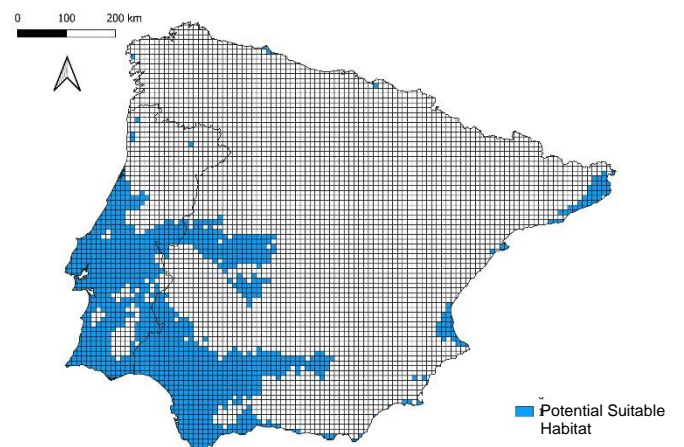


Figure v - Representation and Location of the Potential Suitable Habitat for *Melilotus segetalis*, for the current conditions.

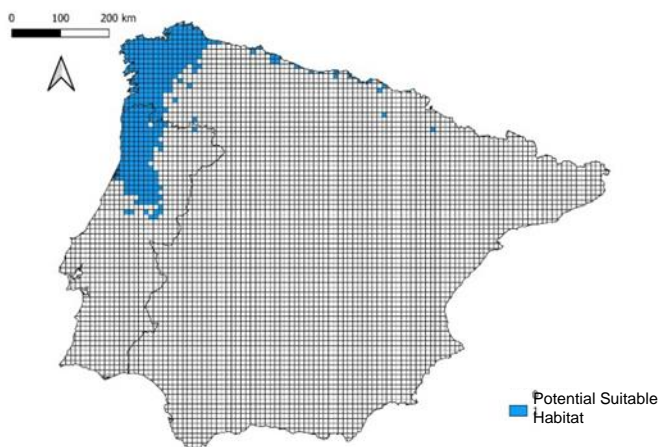


Figure viii - Representation and Location of the Potential Suitable Habitat for *Narcissus cyclamineus*, for the current conditions.

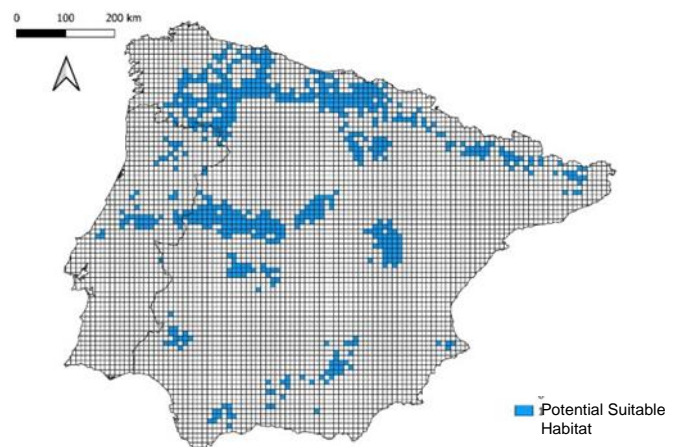


Figure vii - Representation and Location of the Potential Suitable Habitat for *Rhaponticum exaltatum*, for the current conditions.

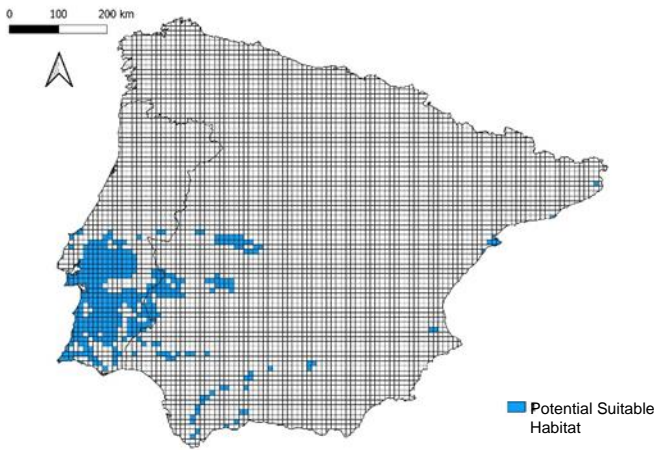


Figure x - Representation and Location of the Potential Suitable Habitat for *Thymus capitellatus*, for the current conditions.

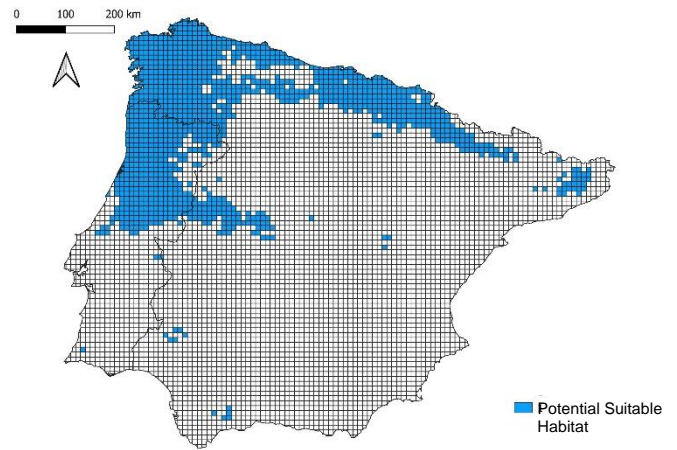


Figure ix - Representation and Location of the Potential Suitable Habitat for *Veronica micrantha*, for the current conditions.

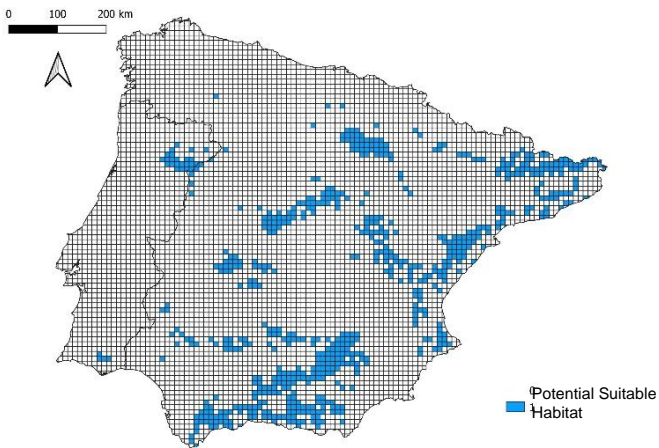


Figure xi - Representation and Location of the Potential Suitable Habitat for *Viola cazorlensis*, for the current conditions.

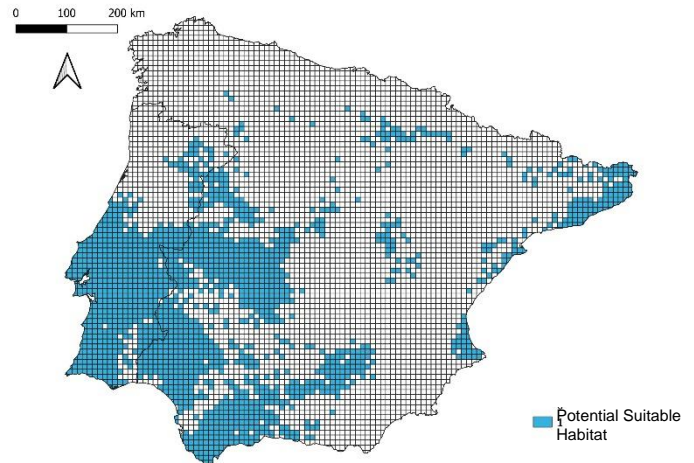


Figure xii - Representation and Location of the Potential Suitable Habitat for *Xiphion vulgare*, for the current conditions.

NAC	Loss	Stable 0	Stable 1	Gain	Loss (%)	Gain (%)	Range Change (%)	Current Range Size	Future Range Size
ATRBAE	80	5389	607	2	11,64	0,29	-11,35	687	609
DORPEN	345	4317	1304	112	20,92	6,79	-14,13	1649	1416
EUPNEV	91	4633	1323	31	6,44	2,19	-4,24	1414	1354
JUNVAL	224	5336	518	0	30,19	0,00	-30,19	742	841
GALNIV	46	5191	813	28	5,36	3,26	-2,10	859	518
MELSEG	143	4782	1145	8	11,10	0,62	-10,48	1288	1153
NARCYC	31	5652	393	2	7,31	0,47	-6,84	424	395
RHAEXA	48	5317	645	68	6,93	9,81	2,89	693	713
THYCAP	44	5637	373	24	10,55	5,76	-4,80	417	397
VERMIC	26	4793	1241	18	2,05	1,42	-0,63	1267	1259
VIOCAZ	67	5384	613	14	9,85	2,06	-7,79	680	627
XIPVUL	167	4204	1612	95	9,39	5,34	-4,05	1779	1707
mean	109,33	5052,92	882,25	33,50	10,98	3,17	-7,81	991,58	915,75

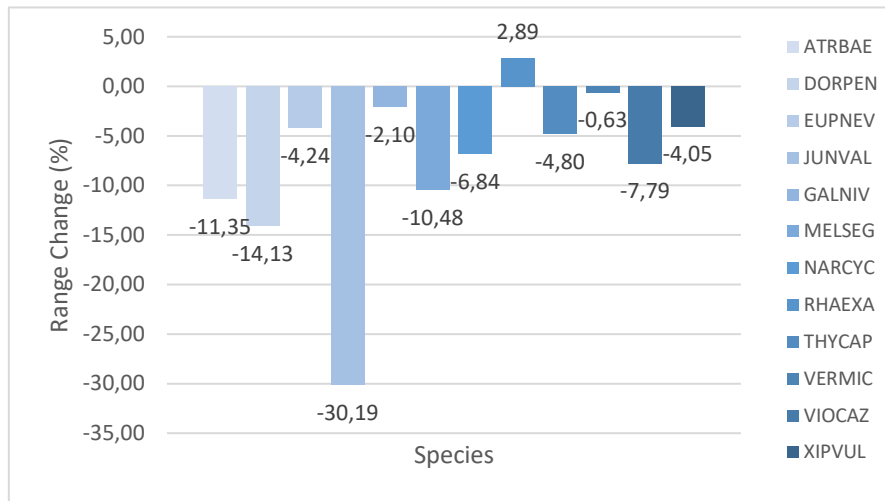


Figure xiii - Representation of the Species Range Change values of the twelve study species for the scenario Nature As Culture, in percentage.

Table x - Results of the study species for the scenario Nature For Nature, in grid units.

NFN	Loss	Stable 0	Stable 1	Gain	Loss (%)	Gain (%)	Range Change (%)	Current Range Size	Future Range Size
ATRBAE	97	5388	590	3	14,12	0,44	-13,68	687	593
DORPEN	356	4275	1293	154	21,59	9,34	-12,25	1649	1447
EUPNEV	88	4631	1326	33	6,22	2,33	-3,89	1414	1359
GALNIV	46	5174	813	45	5,36	5,24	-0,12	859	858
JUNVAL	234	5334	508	2	31,54	0,27	-31,27	742	510
MELSEG	128	4777	1160	13	9,94	1,01	-8,93	1288	1173
NARCYC	6	5651	418	3	1,42	0,71	-0,71	424	421
RHAEXA	62	5314	631	71	8,95	10,25	1,30	693	702
THYCAP	47	5637	370	24	11,27	5,76	-5,52	417	394
VERMIC	31	4794	1236	17	2,45	1,34	-1,10	1267	1253
VIOCAZ	77	5380	603	18	11,32	2,65	-8,68	680	621
XIPVUL	120	4171	1659	128	6,75	7,20	0,45	1779	1787
mean	107,67	5043,83	883,92	42,58	10,91	3,88	-7,03	991,58	926,50

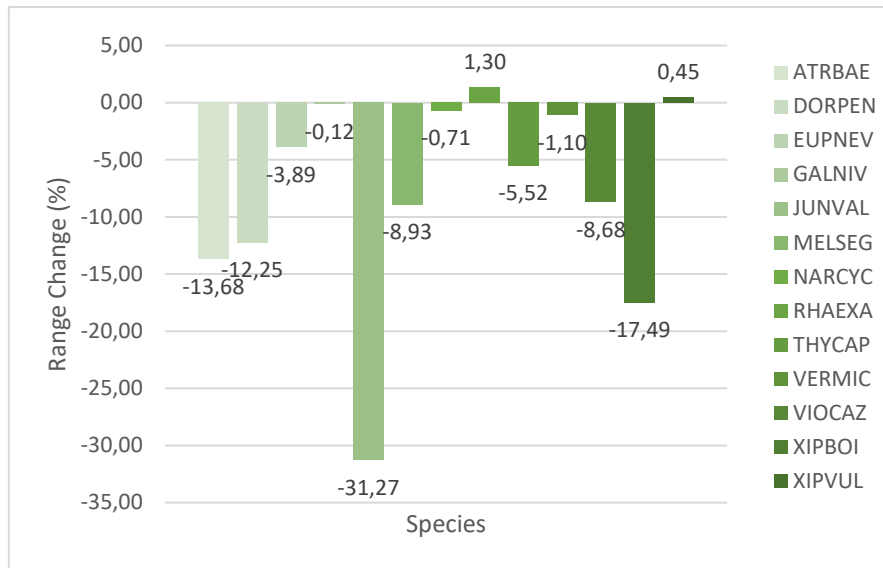


Figure xiv - Representation of the Species Range Change values of the twelve study species for the scenario Nature For Nature, in percentage.

Table xi - Results of the study species for the scenario Nature For Society, in grid units.

NFS	Loss	Stable 0	Stable 1	Gain	Loss (%)	Gain (%)	Range Change (%)	Current Range Size	Future Range Size
ATRBAE	130	5384	557	7	18,92	1,02	-17,90	687	564
DORPEN	417	4232	1232	197	25,29	11,95	-13,34	1649	1429
EUPNEV	95	4607	1319	57	6,72	4,03	-2,69	1414	1376
GALNIV	59	5178	800	41	6,87	4,77	-2,10	859	841
JUNVAL	229	5334	513	2	30,86	0,27	-30,59	742	515
MELSEG	131	4782	1157	8	10,17	0,62	-9,55	1288	1165
NARCYC	25	5651	399	3	5,90	0,71	-5,19	424	402
RHAEXA	92	5339	601	46	13,28	6,64	-6,64	693	647
THYCAP	49	5635	368	26	11,75	6,24	-5,52	417	394
VERMIC	32	4793	1235	18	2,53	1,42	-1,10	1267	1253
VIOCAZ	127	5339	553	59	18,68	8,68	-10,00	680	612
XIPVUL	208	4184	1571	115	11,69	6,46	-5,23	1779	1686
mean	132,83	5038,17	858,75	48,25	13,56	4,40	-9,15	991,58	907,00

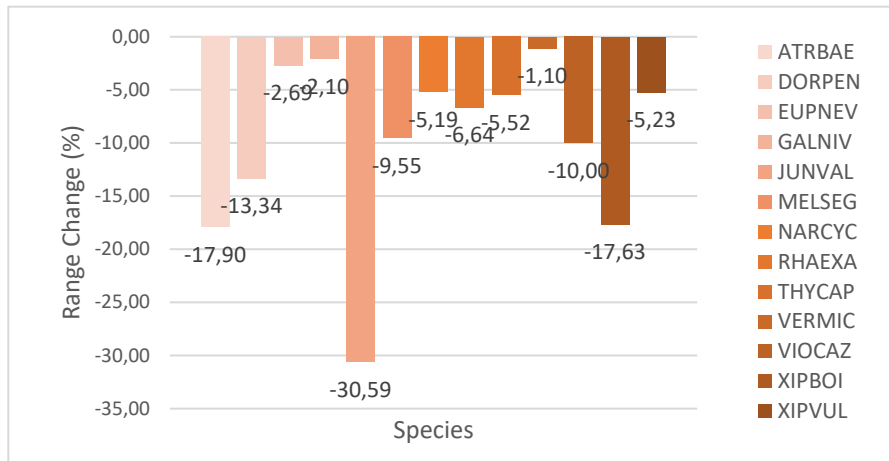


Figure xv - Representation of the Species Range Change values of the twelve study species for the scenario Nature For Society, in percentage.